The Effect on Water Quality of Explosives Use in Surface Mining

Volume 1

MOE Technical Report 4

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Yours truly,

L W Pommen

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Resource Quality Section
Water Management Branch

LWP/cm

enclosure

BC
Ministry of Environment

THE EFFECT ON WATER QUALITY OF EXPLOSIVES USE IN SURFACE MINING

VOLUME 1: NITROGEN SOURCES, WATER QUALITY, AND PREDICTION AND MANAGEMENT OF IMPACTS

MOE Technical Report 4

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WATER MANAGEMENT BRANCH

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SUMMARY

The effects on water quality of explosives use in surface mining were studied at the Fording Coal Limited mine in southeast British Columbia during 1979-80. The results are reported in 3 volumes:

Volume 1: Nitrogen Sources, Water Quality and Prediction and Management of Impacts
Volume 2: Effects on Algal Growth
Volume 3: Nitrogen Release from Coal and Mine Waste.

Key findings of the study are:

- The use of nitrogen-based explosives in surface mining has the potential to impair water quality for drinking, aquatic life and recreation due to the toxicity of nitrate, nitrite and ammonia, and their role in promoting algal growth.

- Most (~ 95%) of the nitrogen discharged from the Fording Coal mine was derived from explosives.

- Nitrogen discharged from the mine in water was equivalent to 6% of the nitrogen in the explosives used. The other 94% of the nitrogen in the explosives is assumed to have entered the atmosphere during detonation as nitrogenous gases.

- The wet blasting conditions at the mine, as evidenced by the predominant use of slurry explosives, appeared to worsen nitrogen losses from the mine.

- The nitrogen discharged from the mine was mainly nitrate, with relatively small amounts of more toxic ammonia and nitrite.

- Nitrate, nitrite and ammonia in the Fording River occasionally exceeded water quality criteria for drinking water or aquatic life during winter low flows.

- Ample nitrogen was available in the Fording River for algal growth, but growth was limited by low phosphorus levels.

- Spoil at Fording Coal contained six times more soluble nitrogen than coal, and it was expected that the soluble nitrogen in fresh spoil would be leached out within one year at the Fording Coal mine.

- Water quality objectives for nitrogen compounds in the Fording River were recommended.

- Techniques for predicting and managing impacts due to nitrogen from explosives were recommended.

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Copies of this report may be obtained from the Reports Library, Water Management Branch, Ministry of Environment, Parliament Buildings, Victoria, B.C.

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1. INTRODUCTION

Increased nitrogen levels in the Fording River at Fording Coal Limited's surface coal mine in southeastern British Columbia were first noticed in 1975-76 during a water quality study of the Elk River basin (Figure 1). The nitrogen was believed to have come from the leaching of residual ammonium nitrate explosives from the mine[1]. Further monitoring by the Ministry of Environment and Fording Coal Ltd. during 1976-78 indicated that nitrogen was reaching potentially harmful levels in the Fording River. Little was known about the effects of explosives use on water quality at that time, and there were numerous surface coal and metal mines being proposed for British Columbia. For these reasons, the Ministry of Environment, with the cooperation of Fording Coal Ltd., initiated a one year study in 1979 of explosives use and its effect on water quality at the Fording Coal mine.

The objectives of the study were:

(i) to determine quantitatively the relationship between explosives use at the mine and the effect on the water quality of the Fording River;

(ii) to use this relationship to aid in the management of impacts on water quality at Fording Coal, and to aid in the prediction and management of impacts at proposed mines in the province.

Field studies at Fording Coal Ltd. began in July 1979 and were completed in July 1980. Information was collected on: explosives use; nitrogen concentrations and loadings in mine drainages and the Fording River; algal growth in the river; and the leaching of nitrogen from coal and spoil. The results of these studies are contained in 3 volumes:

Volume 1: Nitrogen Sources, Water Quality, and Prediction and Management of Impacts by L.W. Pommen

Volume 2: Effects on Algal Growth by R.N. Nordin

Volume 3: Nitrogen Release from Coal and Mine Waste by N.K. Nagpal.

2. LITERATURE REVIEW

To complement the studies conducted at Fording Coal Ltd., literature reviews were conducted on five topics:

- Explosives Use in Surface Mining
- The Nitrogen Cycle
- Experience at Other Mines
- Water Quality Criteria for Nitrogen Compounds
- Nitrogen Removal Methods

Key information from these literature reviews is presented in the following sections.

2.1 EXPLOSIVES USE IN SURFACE MINING

2.1.1 INTRODUCTION

Blasting explosives can be grouped into three basic types: nitroglycerine-base explosives (the dynamites); dry ammonium nitrate/fuel oil mixtures, known by the generic abbreviation of AN/FO; and slurry/water gel explosives which contain ammonium nitrate in solution with various other substances in an aqueous suspension[2]. Dynamites were once the standard explosive of the mining industry, but have now been almost totally replaced by AN/FO and slurries which are cheaper and safer than dynamites[3,4]. Consequently, the following discussion is limited to AN/FO and slurry/water gels.

2.1.2 AN/FO

Ammonium nitrate mixed with fuel oil was introduced as a bulk explosive in surface mining in the early 1950's[3,4] and in 1975 accounted for 45 percent of the explosives producted in Canada[2]. The basic AN/FO mixture consists of 94 percent (by weight) ammonium nitrate (NH_4NO_3) prills and

6 percent fuel oil, and is the cheapest explosive available[4]. Ammonium nitrate is the oxidizer, while fuel oil provides the carbon fuel. The mixture is detonated with a TNT primer, producing gases (mainly N_2, CO_2, and H_2O, with small amounts of CO, N_2O, NO, NO_2, NH_3, and CH_4) that exert a tremendous pressure as they expand at high temperature in the confined space of a blasthole[4]. Powdered aluminum (up to ~ 15 percent by weight) is a fuel that is sometimes added to the basic AN/FO mixture to increase its explosive strength[3,4]. Normally, ammonium nitrate prills, fuel oil and aluminum are loaded into separate tanks on a bulk mix truck, and are mixed together to form the explosive just before the mixture is pneumatically loaded into the blasthole[3].

A major drawback of the dry AN/FO and Al/AN/FO mixtures is that they have no resistance to water attack, and thus cannot be used in wet blastholes unless the hole is dewatered and fitted with polyethylene tubing before loading[3,4]. Ammonium nitrate is extremely water soluble (1183 gL^{-1} in cold water)[5], and any increase in moisture content will cause the explosive to lose strength, with failure to detonate occurring at as low as 5 percent moisture content[3].

The basic AN/FO mixture (94% NH_4NO_3, 6% fuel oil) contains 33 percent nitrogen (as N) by weight of extremely water soluble ammonium (NH_4^+) and nitrate (NO_3^-) ions. Al/AN/FO mixtures contain slightly less nitrogen because the aluminum replaces part of the ammonium nitrate in the mixture.

2.1.3 SLURRY/WATER GELS

The lack of water resistance and low bulk strength of AN/FO led to the development of slurry/water gels in the mid 1950's[3]. Slurries were introduced as industrial explosives in 1959[4] and in 1975 accounted for 42 percent of the explosives produced in Canada[2].

There are numerous slurry formulations, but basically, they are mixtures of oxidizers (ammonium nitrate, sodium nitrate, calcium nitrate) and fuels (fuel oil, gilsonite, sulphur, aluminum) in an aqueous medium (typically ~ 15 percent water) thickened with guar gum and jelled with a cross-linking agent[3,4,6]. Chromates are typically used as jelling catalysts[6]. Slurries may also contain various proprietary components as explosive boosters[6]. Slurries have good water resistance once they have jelled, because the cross-linked gum creates a relatively impermeable barrier to prevent leaching of the soluble oxidizing salts by water in the blasthole[3,4]. Normally, the slurry ingredients are loaded into separate tanks on a bulk mix truck, and are mixed to form the explosive just before the mixture is pumped into the blasthole[3]. The mixture is detonated with a TNT primer.

The nitrogen content of slurries vary with the formulation, but typically contain 20-30 percent nitrogen (as N) by weight of extremely water soluble ammonium (NH_4^+) and nitrate (NO_3^-) ions.

2.2 THE NITROGEN CYCLE

2.2.1 INTRODUCTION

The relationships that exist between the various forms of nitrogen and the changes that can occur in nature are illustrated in Figure 2, adapted from Sawyer and McCarty[7]. Explosives use introduces nitrogen to the environment (air, water or soil) as NH_4^+ and NO_3^- (from NH_4NO_3, $CaNO_3$ or $NaNO_3$) and as N_2, NH_3, N_2O, NO and NO_2 gases formed during detonation (see section 3.4.6(b)).

The most important process in the nitrogen cycle governing the fate of nitrogen from explosives use is nitrification. Under aerobic conditions, NH_4^+, NH_3, NO, NO_2 and N_2O are oxidized to NO_2-, a relatively short-lived intermediate, and then to NO_3-. The reverse process, denitrification, occurs under anaerobic conditions when NO_3- is reduced to NO_2- and then to mainly N_2 gas; and can be an important process in the soil-groundwater system.

2.2.2 AMMONIUM (NH_4^+) AND AMMONIA (NH_3)

NH_4^+ and NH_3 exist in equilibrium in the environment[7]:

$$NH_4^+ \rightleftarrows NH_3 + H^+$$

Increasing pH (alkaline conditions) and temperature shift the equilibrium to NH_3 formation, while decreasing pH (acidic conditions) and temperature produce NH_4^+ [8]. The NH_4^+ ion is a cation and is strongly adsorbed to the cation-exchange complex of a soil, and thus is relatively immobile in soils[9]. Alkaline conditions promote the formation of NH_3, which is volatile, and can move from the soil to water and/or the atmosphere[9]. Both NH_4^+ and NH_3 are stable under anaerobic conditions, but under aerobic conditions they are oxidized to NO_3^- by bacteria (nitrification) at a rate that is directly proportional to temperature[7,10]. For example, the application of NH_4^+ fertilizers to soils will result in the oxidation of NH_4^+ to NO_3^- in a few weeks or even days[9]. Both terrestrial and aquatic plants can use NH_4^+ as a nutrient for plant growth[9,11].

2.2.3 NITRATE (NO_3^-)

The NO_3^- ion is an anion, and there is practically no adsorption of NO_3^- by soils, and thus it is highly mobile in the groundwater system[9]. NO_3^- is stable under aerobic conditions[7], although it is utilized as a nutrient by both terrestrial and aquatic plants[9,11]. Under anaerobic conditions, NO_3^- is reduced to N_2 (mainly) or NH_3 by bacteria (denitrification) via the intermediates NO_2^-, NO and N_2O[7,12,13]. The rate of denitrification is directly proportional to temperature, and the bacteria require a soluble organic carbon energy source to perform denitrification[9,10].

Denitrification can be a significant process in the soil-groundwater system under saturated (anaerobic) conditions if there is an adequate soluble carbon energy source. There is generally sufficient carbon in the rooting zone (~ 0 to 1 m) for denitrification, but subsoils may not have enough carbon for denitrification[9]. Kolenbrander[9] indicated that subsoils have a denitrification capacity of only 1-5 mgL^{-1} NO_3^--N (based on available carbon), and concluded that dilution is the most important process in reducing NO_3^--N levels in subsoils.

2.2.4 NITROGENOUS GASES (N_2, NO, NO_2 and N_2O)

These nitrogenous gases are formed as detonation products (see section 3.4.6(b)). N_2 is a stable gas that comprises 78 percent of the atmosphere[14] and is slightly soluble (12-23 mgL^{-1} N at 0-35°C and standard pressure) in water[7]. Certain nitrogen-fixing terrestrial and aquatic plants (e.g. blue-green algae) can utilize N_2 dissolved in water as a nutrient source[7,11].

The nitrogen oxides (NO, NO_2 and N_2O) are unstable and are oxidized to NO_3^- under aerobic conditions[14], and to N_2 under anaerobic conditions[12,13].

2.3 EXPERIENCE AT OTHER MINES

2.3.1 INTRODUCTION

The literature was reviewed to document the experiences of other mines with regard to explosives use and any resulting impacts on water quality. The findings are summarized below for each mine.

2.3.2 BRENDA MINES LTD., PEACHLAND, B.C.

Brenda Mines Ltd. has operated an open pit copper-molybdenum mine located in the headwaters of Peachland and Trepanier Creeks since the late 1960's. Results of the water sampling program disclosed elevated nitrate levels in Peachland Creek downstream from mining operations. B.C. Research[15] was commissioned to undertake a study to establish the source of nitrate. During their 1976-78 study, B.C. Research found elevated nitrate levels (commonly 15-30 mgL^{-1} NO_3^--N) in the drainage from waste rock piles at the mine. About 7-8 ty^{-1} N was originating from the mine, and it was concluded that this level of nitrogen loss was compatible with predicted losses of blasting mixture. About 2500 t of ammonium nitrate explosives (mostly AN/FO)[16] were used annually* at the mine. (The nitrogen content of 2500 t of AN/FO is 0.33 x 2500 t = 825 t N). Losses of ammonium nitrate were attributed to spillage, hang-up of explosives in the upper portion of blasting holes, and incomplete conversion of the explosives[15].

The nitrate from the mine was believed to be a factor in causing profuse attached algal growth in a 75-100 m reach of Peachland Creek at the outlet of Peachland Lake during late winter-early spring. The nitrate concentrations entering Peachland Lake from the mine were 1-8 mgL^{-1} NO_3-N[15].

To control the quantity of nitrogen leaving the mine, Brenda Mines Ltd. has diverted waste rock pile drainage to its tailings recycle pond, and has constructed a pipeline system to convey water from above the mine around and through the waste rock piles to prevent the water from coming in contact with drainage from the piles. The changes to the drainage system were completed in mid 1980, and at the time of writing it was too early to determine if nitrogen levels in the Peachland Creek system were declining[16].

2.3.3 McINTYRE MINES LTD., GRANDE CACHE, ALBERTA[17]

This surface coal mine is located in west-central Alberta on the eastern slopes of the Rocky Mountains along Sheep Creek. The drainage area of Sheep Creek at the mine is approximately 890 km^2, and minimum winter flows were estimated to be about 1 m^3s^{-1}. The average annual precipitation at Grand Cache was roughly 577 mm.

About 48 x 10^6 bank m^3* of overburden was blasted using ammonium nitrate/fuel oil and placed in spoil dumps during 1971-77. (Assuming a

* bank m^3 = 1 m^3 of in-place, undisturbed rock

powder factor of 0.8 kg explosives bank m^{-3}**, about 38 x 10^6 kg or 38 000 t of explosives would have been used. This is an average of 5500 ty^{-1} over the 7 year period, although closer to 10 000 ty^{-1} were probably used during 1974-77 due to an increased rate of mining. AN/FO contains 33 percent nitrogen, and thus the nitrogen content of the explosives would have been 1800 ty^{-1} N (1971-77 average) and 3300 ty^{-1} N (1974-77 average).

Background nitrate levels at the mine were low (0-0.6 mgL^{-1} NO_3^--N) compared to the levels in drainage from the spoil dumps (2-23 mgL^{-1} NO_3^--N), and in drainage from an ammonium nitrate storage area (>90 mgL^{-1} NO_3^--N on occasion). Nitrate leaching from the spoil dumps took from 0-2 years to develop after spoiling began, and peaked 3-4 years after spoiling began. The increased nitrate levels were attributed to the incorporation in the spoil of spilled ammonium nitrate and nitrous oxide residue produced by blasting.

The nitrate drainage from the mine had no effect on the nitrate levels in Sheep Creek because of the substantial dilution (>60:1) for the mine drainage in Sheep Creek.

2.3.4 CYPRUS ANVIL MINE, FARO, YUKON

Cyprus Anvil Mining Corporation operates a 10 000 td^{-1} open pit lead, silver and zinc mine near Faro, Yukon[18]. About 8 x 10^6 bank m^3 of material is blasted per year at a powder factor of ~ 0.9 kg bank m^{-3}. (Annual explosives use = 8 x 10^6 bank m^3y^{-1} x 0.9 kg bank m^{-3} ≃ 7000 ty^{-1}). Water gels and AN/FO explosives are used[19].

Mine and mill effluent discharged to the tailings pond contained 0.3-2.0 mgL^{-1} NH_3^--N, while the seepage from the tailing pond contained ~ 1 mgL^{-1} NH_3^--N and occasionally more (NO_3^--N and NO_2^--N were not measured). The sources of the nitrogen were thought to be due to losses of unexploded explosives in the pits and spills of explosives[19].

** kg explosives bank m^{-3} = kg of explosives per bank m^3

Dilution for the tailing pond effluent was low (0.3:1 in winter), and there is heavy, extensive algal growth in the discharge streams[19].

2.3.5 ELLIOT LAKE URANIUM MINES, ELLIOT LAKE, ONTARIO

Several authors have reported the occurrence of elevated ammonia and nitrate levels from the underground uranium mining and milling operations at Elliot Lake, Ontario[20,21,22,23]. The elevated nitrogen levels originated from the loss of ammonium nitrate explosives used in blasting, from the loss of ammonia used in the milling process[20,21,22,23] and the loss of nitrate used to elute ion exchange columns[21]. The relative magnitudes of the nitrogen sources was not indicated by the authors. Minewaters typically contained 60-80 mgL^{-1} NH_3-N and 53-350 mgL^{-1} NO_3-N due to residual ammonium nitrate explosives[22]. Techniques recommended to reduce the loss of explosives were: (i) careful handling and usage of explosives to reduce spillage and waste[21,22]; and (ii) reduction of seepage into the mine[22].

The mine effluents were discharged near the headwaters of the Serpent River basin, and the dilution available during summer low flows was very low (0.3-0.5:1)[20]. Nitrate levels in the Serpent River basin exceeded the 10 mgL^{-1} NO_3-N maximum acceptable concentration for drinking water (up to 98 mgL^{-1} NO_3-N), and the total ammonia levels (up to 82 mgL^{-1} NH_3-N)[20] would result in un-ionized ammonia levels that would exceed the safe level for aquatic biota (0.02 mgL^{-1} NH_3) at pH greater than about 6 [24]. It was noted that there was sufficient ammonia from the blasting agents alone to be a problem in the receiving waters under normal pH conditions (~ pH 7)[20]. The elevated nitrogen levels in parts of the Serpent River system create a situation that might cause eutrophication. If future local development in the area provides phosphorus or carbon, which are presently thought to be the limiting factors, eutrophication could become a significant problem[20].

2.3.6 DECKER AND ROSEBUD MINES, MONTANA

These surface coal mines are located in southeastern Montana on the Tongue River Reservoir[25]. The Decker Mine produced ~ 9 x 10^6 t of coal in 1978 [26]. The climate is semiarid (300 mmy^{-1} of precipitation)[27]. Van Voast et al[27,28] found elevated nitrate levels in the effluent from the Decker Mine (0.2-25 mgL^{-1} NO_3-N). Similar nitrate levels were also reported at the Rosebud mine near Colstrip, Montana[27]. It was concluded that the nitrates were probably from ammonium nitrate explosives used in blasting coal and overburden[25,28]. Garrison et al[25] concluded that the elevated nitrate in the Decker mine effluent had no effect on the Tongue River because of the high dilution (500:1 minimum during study) available.

2.3.7 BIG HORN MINE, WYOMING

This surface coal mine is located on the Tongue River in northern Wyoming, just upstream from the Decker Mine in Montana[29]. The mine had been operating for ~ 20 years in 1978, producing ~ 1 x 10^6 t of coal in that year[26]. Nitrogen levels of 0.6-3.6 mgL^{-1} NH_3-N, and 0.3-2.1 mgL^{-1} NO_3-N were measured in the mine effluents[29]. It was suspected that the elevated nitrogen levels were caused by the use of ammonium nitrate explosives[26,29]. The effects on nitrogen levels in the Tongue River were negligible because of the dilution available in the river. Concern was expressed about the cumulative effect of nitrogen loading on eutrophication in the Tongue River with the expansion of mining in the basin[26].

2.3.8 NAVAJO MINE, NEW MEXICO AND EDNA MINE, COLORADO

Significant levels of nitrate were found in saturated soil paste extracts of surface coal mine spoils and in pit water (20 mgL^{-1} NO_3-N), but the origin of the nitrate was not known[30].

2.3.9 MAJOR BRITISH COLUMBIA SURFACE MINES

A brief review of the water and effluent quality data on EQUIS[31] for the fourteen major non-coal surface mines in British Columbia was conducted to identify elevated nitrogen levels. (The major coal mines, Fording Coal Ltd., and B.C. Coal Ltd. are discussed in sections 3 and 4, respectively). The following results were found:

Afton Mines, Kamloops:	No relevant elevated nitrogen levels.
Bethlehem Copper, Highland Valley:	No data.
Brenda Mines, Peachland:	See section 2.3.2.
Cassiar Asbestos, Cassiar:	No data.
Gibralter Mines, Quesnel:	1-2 mgL^{-1} NO_3-N, <5-48 μgL^{-1} NO_2-N, and 0.7-1.2 mgL^{-1} total Kjeldahl N in tailing pond seepage (normally recycled).
Granisle Copper, Babine Lake:	No data.
Lornex Mine, Highland Valley:	4.55 mgL^{-1} NO_2-N plus NO^3-N, and 5 mgL^{-1} total Kjeldahl N in tailing pond supernatant. 4.53 mgL^{-1} NO_2-N plus NO_3-N in pit water[32].
Newmont Mine, Princeton:	No recent elevated nitrogen levels. 1.45 mgL^{-1} NO_3-N, maximum, in tailing pond seepage in the past.

Noranda Mine, Babine Lake:	No data.
Noranda Mine, Boss Mountain:	1.5 mgL^{-1} NO_3-N, 100-525 μgL^{-1} NO_2-N, and 0.2-2.2 mgL^{-1} NH_3-N in tailing pond effluent. 1.1 mgL^{-1} NO_3-N, maximum, in receiving waters downstream from tailing pond.
Placer Development, Endako:	0.6-0.88 mgL^{-1} NH_3-N in tailing pond seepage. 1.05 mgL^{-1} NO_2-N plus NO_3-N, 0.37 mgL^{-1} NH_3-N, and 11 mgL^{-1} total Kjeldahl N in drainage from C.I.L. explosives plant.
Utah Mines, Port Hardy:	2.45 mgL^{-1} NO_2-N plus NO_3-N, and 5 mgL^{-1} total Kjeldahl N in the tailings discharge to Rupert Inlet.
Wesfrob Mines, Tasu:	No data.
Western Mines, Buttle Lake: (now Westmin Resources)	<0.1-0.95 mgL^{-1} NO_3-N and 0.6-6.6 mgL^{-1} NH_3-N in tailings discharge to Buttle Lake. 1.2 mgL^{-1} NO_3-N, maximum, in Buttle Lake.

2.4 WATER QUALITY CRITERIA FOR NITROGEN COMPOUNDS

The nitrogen compounds of concern resulting from explosives use are nitrate, nitrite and ammonia. Water quality criteria for these compounds fall into two categories; those concerned with the health of humans (i.e. drinking water criteria), and those concerned with the health of aquatic life.

2.4.1 DRINKING WATER CRITERIA

(a) Nitrate and Nitrite

The maximum acceptable concentration for nitrate or nitrate plus nitrite in drinking water is 10 mgL^{-1} N [33]. The maximum acceptable concentration for nitrite alone is 1.0 mgL^{-1} N [33]. These limits were established to protect children under the age of 6 months, and particularly under the age of 3 months, from methemoglobinemia. Infantile methemoglobinemia has been related to the use of water containing more than 10 mgL^{-1} NO_2^--N + NO_3^--N to prepare powdered milk formula. In very young infants, nitrate can be converted to nitrite that combines with hemoglobin in the blood to form methemoglobin which does not absorb oxygen. The oxygen carrying capacity of the blood is thus reduced, and death from lack of oxygen can result[24,33,34,35].

Water containing large amounts of nitrate (>23 mgL^{-1} NO_3^--N) is bitter tasting and may cause physiological distress[36] such as diarrhea and diuresis (increased excretion of urine)[37,38].

N-nitroso compounds (nitrosamines, nitrosamides) can be formed in animals and man from their precursors, nitrate, nitrite, amines and amides. N-nitroso compounds have been found to be carcinogenic and teratogenic (causing malformation of the fetus) in animals, but so far cancer in man has not been linked with exposure to N-nitroso compounds or their precursors. There is no evidence at present, but it is highly probable that these compounds may be carcinogenic in man, and thus it has been recommended that exposure to N-nitroso compounds and their precursors should be kept as low as practically achievable[35].

(b) Ammonia

The former acceptable limit for total ammonia (total ammonia = NH_4^+-N plus NH_3^-N) in drinking water of 0.5 mgL^{-1} specified in the 1968

Canadian Drinking Water Standards[37] has been deleted from the 1978 Guidelines for Canadian Drinking Water Quality[33]. The original limit was established for two reasons. First, ammonia interferes with the chlorination of water because it reacts with chlorine to increase chlorine demand (10 parts of chlorine required for 1 part of ammonia), and to form chloramines which have relatively poor disinfection efficiencies. Second, it may promote the growth of organisms and corrosion in water distribution systems[37,39]. The limit was deleted from the 1978 Guidelines[33] because there were no deleterious effects specifically attributable to ammonia, and because guidelines were established for the water quality parameters on which it has a bearing (e.g. coliforms, nitrate, nitrite and chlorine residual)[40].

2.4.2 AQUATIC LIFE CRITERIA

(a) Introduction

The nitrogen compounds resulting from explosives use (nitrate, nitrite and ammonia) can affect aquatic life in 3 ways:

(i) direct toxicity of the compounds;
(ii) reduction of dissolved oxygen during nitrification; and
(iii) as nutrients for aquatic plants.

The toxicity data presented below are for rainbow trout (Salmo gairdneri) and cutthroat trout (Salmo clarki). Rainbow trout is a widely distributed British Columbia sports fish[41], and is the most sensitive fish species to ammonia and nitrite toxicity[24,42]. Cutthroat trout is also a widely distributed sports fish in British Columbia[41], and is the only fish species in the upper Fording River[43,44]. Nitrite and ammonia toxicity data were found only for cutthroat trout fry, but toxicity data were available for all life stages of rainbow trout, which is comparable to cutthroat trout in its susceptibility to nitrite and ammonia toxicity[42,45]. Toxicity data were not found for aquatic organisms other than fish.

Nitrite and ammonia are similar in their toxicity to salmonids, and are likely to be present in water together as a result of explosives use. No data were found on the combined toxicity of ammonia and nitrite in water. Considering the toxic mechanisms of nitrite (reduction of the oxygen carrying capacity of blood) and ammonia (gill damage) it is not unlikely that their toxicities are additive.

(b) Nitrate

Nitrate has a low toxicity to aquatic life, with 4 to 7 day LC_{50} values (concentration at which 50% of test fish die) ranging from 420 to 2000 mgL^{-1} NO_3-N for various species of fish. The respective 4 and 7 day LC_{50} values for fingerling rainbow trout in fresh water were 1360 and 1060 mgL^{-1} NO_3-N [24]. For rainbow trout in hatcheries, Westin[46] recommended a maximum allowable concentration of 56 mgL^{-1} NO_3-N (0.1 of the 7d LC_{10}), and a preferred concentration of 6 mgL^{-1} NO_3-N (0.01 of the 7d LC_{10}) or less. (The preferred concentration appears to be very conservative, and the maximum allowable concentration is probably a more realistic criterion for nitrate).

Nitrate is also an important source of nitrogen for aquatic plant growth. Guideline levels of inorganic nitrogen (NO_3-N + NO_2-N + NH_3-N) suggested to control eutrophication are 0.3 mgL^{-1} N in lakes and 1.0 mgL^{-1} N in free-flowing waters, at the beginning of the growing season[47]. It is not possible to establish a universal criterion for nitrogen that will prevent algal blooms in all kinds of water because suitable conditions with regard to light, phosphorus, substrate, velocity, etc. must also be present for algal growth to occur.

(c) Nitrite

Nitrite is highly toxic to fish. The toxic mechanism in fish is the same as in humans, with nitrite combining with hemoglobin to form methemoglobin, thus reducing the oxygen carrying capacity of the blood[42]. Acute bioassays for cutthroat trout fry (*Salmo clarki*) produced 96 h

LC_{50} values of 0.5-0.6 mgL^{-1} NO_2^--N, and 36 day LC_{50} values of 0.4 mgL^{-1} NO_2^--N. The maximum concentration with no mortalities after 36 days was 0.20 to 0.25 mgL^{-1} NO_2^--N [45].

Acute bioassays on rainbow trout (Salmo gairdneri), which are comparable to cutthroat trout in their susceptibility to acute toxicity from nitrite, produced 96 h LC_{50} values as low as 0.11 mgL^{-1} NO_2^--N[42,48]. The maximum level with no mortality after 10 days was 0.06 mgL^{-1} NO_2^--N [24].

Nitrite toxicity decreases as the pH increases, particularly at high pH (>8.6), and has some dependence on sulphate, phosphate and nitrate concentrations[48]. Nitrite toxicity was found to be markedly dependent on chloride concentration, with 10 mgL^{-1} Cl^- reducing the 96 h LC_{50} by an order of magnitude[48]. Russo et al[48] found that fish size was not a factor in nitrite toxicity, contradicting earlier studies by the same authors[42,45].

Sublethal effects of nitrite on rainbow trout (i.e. increased methemoglobin, decreased hemoglobin) have been observed at levels of 0.015 to 0.10 mgL^{-1} NO_2^--N [42]. B.C. Research[49] concluded that 0.02 mgL^{-1} NO_2^--N should be a guideline as the maximum level acceptable for salmonids for continuous exposure in fish rearing tanks utilizing recycled water.

(d) Ammonia

Ammonia in water assumes an equilibrium between ionized (ammonium - NH_4^+) and un-ionized (ammonia - NH_3) chemical species that is principally dependent upon pH and temperature. Un-ionized ammonia is toxic to fish, while ammonium is considered non-toxic, or at least considerably less toxic[24,45]. Un-ionized ammonia values can be calculated from total ammonia, pH and water temperature measurements, as outlined by Trussell[50]. Un-ionized ammonia values calculated by this method are approximate because the calculations do not consider the formation of ammonia-heavy metal complexes that reduce un-ionized ammonia levels[51].

Acute bioassays on cutthroat trout fry gave 96 h LC_{50} values of 0.4 to 0.7 mgL^{-1} un-ionized NH_3-N, and the maximum concentration with no mortality after 36 days was 0.18 mgL^{-1} un-ionized NH_3-N. Toxicity of un-ionized ammonia to cutthroat trout was caused by damage to the gills, kidneys and livers[45]. Acute bioassays on rainbow trout, which are comparable to cutthroat trout in their susceptibility to ammonia, indicate that juveniles and adults are more susceptible than fry[45]. Consequently, the acute toxicity levels for larger cutthroat trout may be lower than those for fry cited above.

All of the reported acute toxicity (i.e. 1 to 4 day LC_{50}) values for salmonids (including rainbow and cutthroat trout) lie between 0.13 and 0.7 mgL^{-1} un-ionized NH_3-N[52,99], except those of Rice and Stokes[53], which were 0.06 to 0.08 mgL^{-1} un-ionized NH_3-N for rainbow trout (24 h LC_{50}). Intermittent exposure to un-ionized ammonia was found to be more toxic than constant exposure, with 96 h LC_{50} values as low as 0.08 mgL^{-1} NH_3-N[99].

B.C. Research[49] reviewed the literature on the sublethal effects of un-ionized ammonia on fish and noted the following data:

Concentration of Un-ionized Ammonia (μgL^{-1} N)	Effect on Fish	Source
3	Permanent gill damage to chinook salmon after continuous exposure of 6 weeks	Burrows[54] and Trussell[50]
6	Recommended as suitable upper level for continuous exposure	Mayo *et al*[55]
7-9	No effect on rainbow trout at dissolved oxygen levels above 7 mgL^{-1} in multiple reuse operation	Larmoyeux and Piper[56]
25	Maximum level that fish can tolerate over a long period	W.P.R. note[57]

B.C. Research concluded that for continuous exposure of salmonids, un-ionized ammonia levels should not exceed 6-9 μgL^{-1} N, and 7 μgL^{-1} N was judged to be the most suitable upper level.

The U.S. Environmental Protection Agency[24] has recommended a criterion of 16 μgL^{-1} un-ionized NH_3-N (i.e. 20 μgL^{-1} as NH_3) to protect freshwater aquatic life. This criterion was determined by multiplying the lower end of the acute toxicity range (~ 0.2 mgL^{-1} un-ionized NH_3) by an application factor of 0.1.

Ammonia in water is readily oxidized to nitrite and then to nitrate under aerobic conditions. The theoretical oxygen demand for nitrification of ammonia is 4.6 mg O_2 per mg NH_3-N, and thus ammonia may reduce dissolved oxygen levels in water[52]. Nitrite is the intermediate in the nitrification of ammonia, but is rapidly converted to nitrate, and thus is normally present only in trace amounts. However, the second step of nitrification can be inhibted by low temperatures, oxygen deficiency, nitrous acid and un-ionized ammonia, resulting in the buildup of nitrite, which is highly toxic to fish[42,43]. Ammonia and its oxidation products (nitrite and nitrate) are important sources of nitrogen for aquatic plant growth[58,59].

2.5 NITROGEN REMOVAL METHODS

2.5.1 INTRODUCTION

This section presents a survey of the methods available to remove nitrogen from wastewaters, and discusses the suitability of these methods for the removal of nitrogen from wastewater resulting from explosives use.

Explosives use results in the introduction of NO_3^-, NH_3, NH_4^+ and NO_2^- to water. The relative amounts of each compound present in water depends primarily on the time elapsed since the introduction of the explosives to the water. The nitrogen in explosives is comprised of 1/3 to 1/2 NH_4^+, 1/2 to 2/3 NO_3^- and small amounts of NO_2^-. Water recently contaminated by explosives (e.g. explosives plant effluent) will thus contain the above proportions of nitrogen compounds. Immediately after the introduction of explosives to water, the natural transformations of nitrogen compounds begins as outlined in section 2.2 on the Nitrogen Cycle. The net result of the transformations (i.e. NH_4^+ adsorption, NH_3 volatilization, nitrification, denitrification) is to decrease NH_4^+/NH_3 and to increase NO_3^- (NO_2^-, the intermediate between NH_4^+/NH_3 and NO_3^-, is usually present at low levels, but inhibition of the second step of nitrification by nitrous acid, un-ionized ammonia, oxygen deficiency, or low temperatures, can lead to a build-up of NO_2^-[42,43]). Surface mine drainage from pits and spoil piles typically contains predominantly NO_3^- with small amounts of NH_4^+/NH_3 and NO_2^-.

2.5.2 NITROGEN REMOVAL METHODS

(a) Introduction

The various treatment methods for removing nitrogen compounds from water are summarized in Table 1. Only those treatment methods that remove NH_4^+/NH_3 and especially NO_3^- are applicable to the treatment of wastewater resulting from explosives use.

It is necessary to distinguish between those treatment methods that are theoretically possible, and those that have actually been used in full-scale application. As of 1978, only NH_3 stripping, ion exchange for NH_4^+, breakpoint chlorination for NH_4^+/NH_3 and biological nitrification/denitrification were in full scale use[60]. A 1979 study for the Denison Mines Limited and Rio Algom Limited uranium mines at Elliot Lake[61] considered biological nitrification, breakpoint chlorination and ion exchange for ammonia removal and biological denitrification for nitrate removal. Pretreatment and pilot scale process development studies were considered to be essential for each treatment process. A preliminary evaluation of the study indicated that the treatment processes had limited application because the processes could produce additional contaminants or create difficulties with the final disposal of the contaminants. It was noted that biological nitrification-denitrification has never been applied to mining and milling effluents[61]. Mitchell _et_ _al_[62] noted that ammonia stripping, ion exchange (NH_4^+ and NO_3^-), and biological denitrification were complex and costly treatment methods, and not particularly suited to the treatment of large volumes of effluent.

The following is a brief review of the more promising NH_4^+/NH_3 and NO_3^- removal methods for explosives wastewater.

(b) Biological Nitrification and Denitrification

This is a two-step biological treatment process that uses nitrifying bacteria under aerobic conditions to oxidize NH_4^+/NH_3 and NO_2^- to NO_3^- (nitrification) and denitrifying bacteria under anaerobic conditions to reduce NO_3^- to N_2 gas (denitrification)[60,62]. Mine drainage that is well-nitrified would only require the denitrification step. Application of the process to the concentrated and highly variable contaminant levels in explosives plant effluent would require consideration of the toxic effects on the biological systems. The biological process is markedly temperature dependent, with the rate of nitrification or denitrification decreasing rapidly as temperature decreases[60,62]. The low efficiency of the process at low temperatures would be a serious constraint to the application of the process during the winter in B.C. (Except for coastal areas, nitrogen levels would be highest during winter low flows when the process would have its lowest efficiency). To achieve reliable nitrogen removal on a year round basis, the process must be designed for the coldest operating conditions[60]. The denitrification step requires the addition of a biologically degradable soluble organic carbon energy source (usually methanol) to increase the reaction rate to practical levels[60,62].

The costs of biological denitrification (not including nitrification) reported by Culp et al[60] for a one million U.S. gallon per day plant (~ 3800 m^3d^{-1}) were \$500,000 to \$750,000 capital costs and \$60,000 to \$70,000 per year operation/maintenance costs (in 1978 U.S. dollars). Biological nitrification-denitrification has never been applied to mining/milling effluents, and pilot scale studies are considered to be essential[61].

(c) Breakpoint Chlorination

This is a chemical treatment process in which chlorine is used to oxidize NH_4^+/NH_3 to form chloramines[60,63]. The process is rather expensive[63], and the chloramines formed are toxic to fish[24]. A dechlorination treatment step would probably have to follow chlorination to produce an effluent acceptable for discharge to surface water. There were no full-scale applications of the process as of July 1976 [60], and pilot scale studies would be needed[61].

(d) Ammonia Stripping

This is a physical/chemical treatment process in which the pH of the wastewater is raised to 10.8-11.5 (to convert NH_4^+ to NH_3), the NH_3 is then stripped by air or steam-water contact in a stripping tower, and released to the atmosphere. It is reported to be the cheapest, simplest and easiest method to achieve NH_4^+/NH_3 removal[63], and is in full-scale use[60,63], including a mine application[62]. Disadvantages of the process include:

- cannot be operated at air temperatures below 0°C[63]
- NH_3 can create an air pollution problem[63]
- the alkaline effluent would have to be neutralized before discharge to surface water.

(e) Ion Exchange

Selective ion exchange resins have been developed for NH_4^+ (e.g. clinoptilolite)[60,63,64] and NO_3^- (e.g. high molecular weight amidines)[63,64]. The process is expensive[63,64] (~ 10-20 times the cost of ammonia stripping)[63], pretreatment is required (e.g. filtration) to prevent fouling of the resin[61,63], and the concentrated resin regenerant must be disposed of in some manner[60,63]. Pilot scale process development studies would be necessary for mining applications[61].

(f) Land Application

Land application can be divided into irrigation and infiltration/percolation[65]. Irrigation attempts to match the water and nitrogen application rates to plant requirements, while infiltration/percolation attempts to maximize application rates for a given removal efficiency. Both methods involve several processes that transform and remove nitrogen to varying degrees, depending on the method:

Nitrification	- NH_3/NH_4^+ and NO_2^- oxidized to NO_3^- under aerobic conditions (~ 100% conversion) - rate of conversion low at low temperatures - occurs in both irrigation and infiltration
Plant uptake	- NH_3/NH_4^+ and NO_3^- used for plant growth - plant N requirements[60]: forage crops - 170 to 680 kg ha^{-1} y field crops - 85 to 170 kg ha^{-1} y forests - 25 to 115 kg ha^{-1} y - crop must be removed to achieve permanent N removal[60] - 40 to 90% N removal and storage in plant tissue[65] - main N removal mechanism in irrigation, not significant in infiltration
Ammonium adsorption	- NH_4^+ adsorbed on cation exchange complex of soil - occurs in both irrigation and infiltration
Denitrification	- NO_3^- reduced to N_2 gas under anaerobic conditions. Soluble organic carbon energy source required for denitrification to proceed.

- 0 to 50% N removal without addition of soluble carbon source [65] (e.g. methanol)
- 90+% N removal with addition of soluble carbon source
- low efficiency at low temperature
- main N removal mechanism in infiltration, less important in irrigation[60]

3. INVESTIGATIONS AT FORDING COAL LIMITED

3.1 INTRODUCTION

The Fording Coal Limited mine is located in the Kootenay coalfields of southeastern British Columbia near the headwaters of the Fording River, a tributary of the Elk River (Figure 1). The area is mountainous, lying within the Front Ranges of the Rocky Mountains, with an elevation range of 1650 to 2500 m above sea level at the mine. The closest settlement is the District of Elkford located 30 km south of the mine on the Elk River.

Construction of the mine began in 1969 [66], and coal production commenced in late 1971 [67]. The mine and preparation plant achieved their rated capacities in 1975, producing and shipping 3×10^6 ty^{-1} [68]. All of the coal produced comes from surface mining at the present time[68]. An expansion program is now underway to increase production to 5×10^6 ty^{-1} by 1983 [69], and a further expansion to 6.5×10^6 ty^{-1} has been proposed[70]. Significant explosives use at Fording Coal began in 1971.

3.2 MINE DESCRIPTION

The mine straddles the Fording River between Henretta and Kilmarnock Creeks at elevations ranging from 1700 to 2200 m above sea level. The Fording Valley runs north-south, with Eagle and Turnbull Mountains to the east and the Greenhills Range to the west (Figure 3).

The layout of the mine is shown in Figure 4. From the start of mining in 1971, to mid-1980, approximately 100×10^6 bank m^3 of rock was blasted, excavated and dumped in spoil piles at the mine. About 66×10^6 bank m^3 of rock was removed from the Clode, Turnbull and Taylor pits, and was dumped on the east side of the river. The largest pit at the mine was the Clode, from which 55×10^6 bank m^3 of rock was removed during 1971 to mid-1980. The Clode pit was exhausted by mid-1980, and is being replaced by the Taylor Pit which started production in 1979, and is scheduled to produce 2 x 10^6 ty^{-1} of coal for the next 10 years[68,69]. All of Eagle Mountain may be mined as one large open pit in the future[70].

About 34 x 10^6 bank m^3 of rock was removed from the Greenhills pits during 1971 to mid-1980, and was dumped on the west side of the river. The Greenhills pits will continue to be expanded in the future[69].

Raw coal from the pits is washed in the preparation plant, and tailings from the plant were deposited in the North tailing pond until April 1979, and in the South tailing pond since that time. Tailings pond supernatant is recycled to the preparation plant.

Water supply for the mine is obtained from several sources. There are wells adjacent to the Fording River upstream from the Clode settling pond that supply domestic and process water. Process water for the preparation plant is also obtained from mine surface runoff, pit dewatering and pumping or diversion from the Fording River to the tailings ponds. Mine drainage not discharged to the tailing ponds is directed to settling ponds prior to discharge to the Fording River. Domestic sewage was treated in an oxidation ditch prior to discharge to the North Loop settling pond. (A new sewage treatment plant located south of Kilmarnock Creek, that discharges to the ground, began operation on October 1, 1981).

3.3 CLIMATE AND HYDROLOGY

The mean monthly total precipitation, snowfall and temperature data at Fording Coal Ltd. for the period 1970-1979 are presented in Figure 5. Precipitation is heaviest in December and January (as snow), with smaller, roughly uniform amounts falling in the other months of the year. Annual precipitation has ranged from 500 to 1000 mm, with a nine-year mean of 715 mm. Average annual potential evapotranspiration is roughly 460 mm[96]. Air temperatures below 0°C are normally experienced during November through April, and about 50 percent of the annual precipitation falls as snow during this period. Air temperatures have ranged from -40°C in winter to 35°C in summer.

The precipitation and air temperature at Fording coal during the study period, July 1979 to June 1980, are summarized in Figure 6. Precipitation during January - November 1979 was the lowest in 10 years of record (54 percent below average), while precipitation during December 1979 - June 1980 was 36 percent above average. Freezing temperatures were experienced from mid October to mid May, with 3 short thaws of 3 to 8 days each.

Streamflow data for the Fording River at Fording Coal Ltd. for the period 1971-80 are summarized in Table 2. Streamflows are characterized by peak flows in May and June due to spring snowmelt, and then a steady decline during summer and fall, with minimum flows occurring in winter (December through March). Flows have ranged from a daily maximum of 33 m^3s^{-1} in June 1974 to a daily minimum of 0.09 m^3s^{-1} in January 1980. Runoff in the Fording River at the mine has averaged about 80 percent of the total precipitation measured at the mine.

1979 was the driest year in 10 years, and consequently streamflows during much of the July 1979 to June 1980 study period were very low. Streamflows during August 1979 through March 1980 were the lowest in 10 years. Streamflows in April and May 1980 were well above average due to an above average snowpack and an early snowmelt.

3.4 EXPLOSIVES USE AT FORDING COAL

3.4.1 INTRODUCTION

Explosives use at Fording coal began in 1971, and AN/FO, Al/AN/FO and several slurry formulations have been used. The explosives are manufactured at the mine by CIL Inc., who load the explosives into blastholes drilled by Fording Coal. Priming and detonation of explosives is done by Fording Coal.

3.4.2 EXPLOSIVES MANUFACTURE

The ingredients for the explosives are delivered to the mine by railway or truck, and are stored at the CIL explosives plant. The only ingredients mixed at the explosives plant are dry sodium nitrate ($NaNO_3$) or calcium nitrate ($Ca(NO_3)_2$) and hot ammonium nitrate (NH_4NO_3) solution to form a liquor that is used in the formulation of slurries. The liquor and other ingredients are loaded into separate hoppers or tanks on bulk mix trucks at the explosives plant. The bulk mix trucks convey the ingredients to the blast pattern, mix the ingredients in calibrated proportions to form the explosive, and pump (slurry) or blow (AN/FO) the explosive into blastholes that have been primed with TNT primers and primer cord.

3.4.3 BLASTHOLE LOADING

The blastholes are 0.25 m or 0.31 m in diameter and drilled in patterns ranging from 6 to 11 m square, depending on hole diameter, and whether the pattern is in a truck/shovel or dragline pit. The blastholes in the truck/shovel pits are typically about 15 m in depth, while the blastholes in the dragline pits range up to 45 m in depth[68]. The blastholes are partly filled with explosives (typically to within 6-7 m of the surface), and then filled with the rock chips generated during drilling. A typical 15 m truck/shovel blasthole would contain from 350 to 700 kg of explosives depending on the hole diameter and explosive type. About 15 000 blastholes were loaded at Fording Coal during 1979. An average blast at Fording Coal in 1980 would have involved 360 000 kg of explosives to break 420 000 bank m^3 of rock[68].

3.4.4 NITROGEN CONTENT OF EXPLOSIVES

The principal nitrogen compounds in the explosives used at Fording Coal were ammonium nitrate (NH_4NO_3) in AN/FO and Al/AN/FO, ammonium nitrate and sodium nitrate ($NaNO_3$) in the Nitrex slurry series used from 1972 to May 1980, and ammonium nitrate and calcium nitrate ($Ca(NO_3)_2$) in the

Power Gel slurry series that was introduced in May 1980. These compounds are extremely soluble in water with solubilities in cold water of: NH_4NO_3 - 1183 gL^{-1}; $NaNO_3$ - 921 gL^{-1}; and $Ca(NO_3)_2$ - 1212 gL^{-1} [5]. Nitrogen is present in the form of NH_4^+ and NO_3^- ions upon dissolving in water.

The nitrogen content by weight (as N) of these explosives is 33 percent for AN/FO, 31 percent for Al/AN/FO, 21-25 percent for the Nitrex slurry series and 21-24 percent for the Power Gel series[71,72,75].

3.4.5 EXPLOSIVES USE

The explosives use at Fording Coal from 1971 to mid 1980 is summarized in Figure 7, 8, 9 and 10. Figures 7 and 8 show the annual and cumulative explosives use expressed in tonnes of explosives (Figure 7) and in tonnes of nitrogen (Figure 8). The largest annual use occurred in 1977 when 15 000 t of explosives containing 3300 t of nitrogen was used. By mid 1980, (end of the study period) a cumulative total of 80 000 t of explosives containing 20 000 t of nitrogen had been used.

Figures 7 and 8 also show a breakdown of the amounts of dry AN/FO plus Al/AN/FO and slurry used. The use of dry explosives predominated during the early life of the mine (1971-74), when mining occurred on the mountain tops and/or above the groundwater table. As mining proceeded to greater depths, and intersected the groundwater table, the use of the water-resistant slurry explosives predominated (1975-80).

Figure 9 shows the annual and cumulative explosives use (in tonnes of nitrogen) broken down by pit. The pits have been grouped into those east of the Fording River (Clode, Repeat 4, Turnbull and Taylor pits), and those west of the Fording River (Greenhills pits - north, south, F-seam and K-seam). For the period 1971 to mid 1980, 66 percent of the total explosives (~ 13 000 t N) was used in pits east of the Fording river, mainly in the Clode pit (55 percent of the total, ~ 11 000 t N). While only 34 percent of the 1971 to mid 1980 explosives (~ 7000 t N) was used west of the river in the Greenhills pits, explosives use in the Greenhills has been increasing, and surpassed that used east of the river during 1979-80.

Figure 10 illustrates the monthly explosives use by pit for the period January 1979 to June 1980, which includes the intensive sampling period of this study (July 1979 to June 1980). The figure shows the continuous nature of drilling and blasting activity throughout the year. The influence of explosives use on water quality is governed mainly by the annual hydrologic cycle and mine hydrology, rather than by seasonal fluctuations in explosives use (see sections 3.5 and 3.6).

The powder factor or blasting ratio (weight of explosives used per bank volume of material blasted) at Fording Coal has varied from 0.56 to 0.98 kg bank m^{-3} during 1971-79, with a weighted average of 0.8 kg bank m^{-3}. Considering the nitrogen content of the explosives, a weighted average of 0.2 kg N bank m^{-3}* was used during 1971-79.

Fording Coal has made several changes in its blasting practices since this study was done, which will tend to reduce nitrogen losses. These include:

- a lower powder factor due to use of a larger drill pattern;
- increased use of AN/FO and polyethylene blasthole liners;
- smaller, more frequent blasts, resulting in reduced loading to blasting time[97].

3.4.6 NITROGEN LOSSES FROM EXPLOSIVES USE

Nitrogen losses to water during explosives use occur through contact between water and the nitrogen compounds in the explosives, and between water and the nitrogen compounds produced during detonation.

* kg N bank m^{-3} = kg of nitrogen per bank m^3.

(a) Water-Explosives Contact

The nitrogen compounds used in explosives are extremely soluble in water, and any contact between water and these compounds either before detonation, or after detonation in the case of explosives that did not detonate, will result in nitrogen losses to water.

The first potential point of nitrogen loss occurs at explosives receiving/storage/blending/handling facilities because of spills of nitrogen compounds during unloading, blending and loading operations. The magnitude of the nitrogen loss will depend on the effectiveness of methods for spill containment, dry clean-up, and the return to storage of the nitrogen compound. Subsequent water contact with the spill area (e.g. floors, yard areas, equipment, trucks) via washdown, precipitation or snowmelt will dissolve any residual nitrogen compounds. Nitrogen losses to water at the C.I.L. Inc. explosives plant at Fording Coal Ltd. are discussed in section 3.5.2(c).

Spills can also occur on the blasting pattern when bulk mix trucks are loading blastholes. Any explosives that are spilled on the ground surface will not detonate, but will remain in the spoil and will be susceptible to leaching. Spills on the blasting pattern at Fording Coal Ltd. appeared to be relatively minor, with the exception of the practice of flushing the mixing chamber and hose of slurry mix trucks on the ground during a delay or when the truck was empty. About 70 kg of slurry containing ~ 15 kg of nitrogen that may be fairly susceptible to leaching because the guar gum and crosslinker are shut off during flushing, is discharged per flush[72].

Once the explosives are in the blasthole there are several ways in which losses to water can occur. Dry AN/FO explosives have no resistance to water, and any water in the blasthole will begin dissolving the nitrogen compounds resulting in a partial, or ultimately, in a complete misfire of the charge. AN/FO will not detonate if the moisture content exceeds as little as 5 percent, and this material will remain in the spoil, and will be susceptible to leaching. Normal safety practice requires that all misfired AN/FO charges be completely washed from the blasthole[73,74], thus causing substantial nitrogen loss to water. Another cause of losses when using AN/FO is the hang-up of the explosive in the upper portion of the blasthole. This portion of the explosive does not detonate, and thus is available in the spoil for leaching[15].

Fording Coal Ltd. had used relatively little AN/FO since 1975 because of the wet conditions in the pits. There were some large AN/FO misfires (~ 50 000 kg or more) in the Clode Pit in the past, but records of these misfires were not available[75].

Slurry explosives have good resistance to water, but nitrogen losses can occur in wet blastholes before the water-proofing sets up. Slurries are water-proofed using guar gum and crosslinkers, but it takes 1-2 minutes for the crosslinking to set up, and the nitrogen compounds are susceptible to water attack during this time. To avoid plugging the mixing chamber and hose when mixing slurry in a bulk mix truck, the guar gum and crosslinkers are the last ingredients to be turned on, and the first to be shut off. This means that an unknown quantity of nitrogen compounds is unprotected from water attack at the start and finish of loading. The practice of flushing the mixing chamber and hose onto the ground or into the blasthole after a delay in loading or when the truck is empty was discussed earlier. Slurry can also enter the cracks and fractures in the sides of the blasthole where it will not detonate[97].

Wet blastholes at Fording Coal Ltd. were monitored before and after loading with slurry, and it was found that about 1 to 2 percent of the nitrogen in the slurry was lost to water (see section 3.4.6(c)).

There is also some evidence that slurry may be somewhat susceptible to water attack even after the water-proofing has set up. Bauer _et_ _al_[3] immersed packaged slurries in water for one week before detonation, and found a decrease in velocity of detonation and an increase in critical diameter due to water attack. Fording Coal Ltd. has indicated that they have had no misfires when using slurry[75]. Typically, the slurry is in the blasthole for one week before detonation, but slurry has been detonated successfully after being in blastholes for up to 6 months[72,75].

(b) Water-Detonation Products Contact

Detonation of explosives that use ammonium nitrate/sodium nitrate/ calcium nitrate as oxidizers produces several nitrogenous gases. These include mainly nitrogen (N_2), and small amounts of ammonia (NH_3), and at least three oxides of nitrogen: nitrous oxide (N_2O); nitric oxide (NO); and nitrogen dioxide (NO_2)[4,14,76]. Most of the nitrogen in explosives enters the atmosphere as nitrogenous gases during detonation.

Nitrogen (N_2) is only slightly water soluble (12 to 23 mgL^{-1} N at 0 to 35°C and standard pressure), and the rate of oxidation of N_2 to NO_3^- is very slow[14], and thus the production of N_2 does not contribute NO_3^-, NO_2^- or NH_3 to water. Ammonia gas (NH_3) is extremely water soluble (899 gL^{-1})[5], and thus any NH_3 gas produced that comes in contact with water would contribute NH_3 and subsequently NH_4^+, NO_2^- and NO_3^- to the water.

Nitrous oxide gas (N_2O) is moderately soluble in water (~ 2500 mgL^{-1} at STP)[5] and is oxidized to NO_3^- in water[14], and thus could contribute NO_2^- and NO_3^- to any water that it contacts. Hackbarth[17] attributed the increase in nitrate in water at a surface mine in Alberta to ammonium nitrate spills and the nitrous oxide residue produced by blasting (section 2.3.3). Nitric oxide (NO) is slightly soluble in water (~ 100 mgL^{-1} at STP)[5], but is rapidly oxidized to nitrogen dioxide (NO_2) in the presence of oxygen[14,76]. NO_2 gas and its dimer, nitrogen tetroxide or peroxide (N_2O_4) that is formed as NO_2 cools, are both water soluble[5,14]. Both NO_2 and N_2O_4 dissolve in water to form HNO_3 and NO that dissociate or oxidize in water to yield NO_3^- ions[14].

C.I.L. Inc. has estimated nitrogen oxide production to be about 3 Lkg^{-1} of explosives[77] (standard temperature and pressure are assumed). This is equivalent to about 2-4 kg N t^{-1} of explosives, depending on the relative amounts of N_2O, NO and NO_2 present. The nitrogen content of explosives typically ranges from 20-33 percent, and thus the nitrogen oxide production rate would be equivalent to 2-4 kg N per 200-330 kg N in 1 t of explosives, or 0.6-2 percent of the nitrogen content of the explosives.

It is expected that most of the nitrogen oxide and ammonia gases produced during detonation are released to the atmosphere, but it is probable that some of the gases remain in the spoil where they can dissolve in water. The nitrogenous gases released to the atmosphere will ultimately return to the earth via precipitation or dry deposition at some distance from the mine, depending on the prevailing atmospheric conditions[78].

(c) Nitrogen Losses from Loading Wet Blastholes with Slurry

To evaluate the loss of nitrogen to groundwater when loading wet blastholes with slurry explosives, the water in blastholes at Fording Coal was monitored for nitrogen before and after loading. Before loading, the diameter of the hole and the depth of water in the hole were measured to compute the volume of water in the hole, and a single water sample for nitrogen analysis was taken at mid-depth in the water column using a Wildco Kemmerer sampler. After loading, the depth of water in the hole overlying the slurry was measured to compute the volume of water, and water samples were taken at the top, mid-depth and bottom of the water column, and composited for nitrogen analysis.

Monitoring was conducted on holes loaded with Nitrex 201 and Powergel A slurries, and these results are summarized in Table 3. Before loading, the dissolved inorganic nitrogen concentrations in the water in the blastholes ranged from 12 to 145 mgL^{-1} N (50 mgL^{-1} N, average). The weight of nitrogen in the water ranged from 0.01 to 0.1 kg N per hole (0.05 kg N per hole, average). Most of the nitrogen present in the water before loading was probably due to previous losses of explosives to groundwater because the holes sampled were several benches down in the pits.

The nitrogen concentrations in the water after loading were 1 to 2 orders of magnitude higher than before loading, ranging from 460 to 57 800 mgL^{-1} N (10 200 mgL^{-1}, average). The net increase in the weight of nitrogen in the water ranged from 0.3 to 23-45 kg N per hole (4.2-6.8 kg per hole, average). (A range is shown for most of the weights of nitrogen per hole because there was usually a loss of water from the hole during loading. The lower value is based on the volume of water after loading, while the higher value is based on the volume of water before loading. The actual loss of nitrogen to groundwater lies between these two values). The values represent the immediate losses of nitrogen to groundwater, which are considered to be minimum losses, because the technique used could not measure the total amount of nitrogen that was lost to water.

The Nitrex 201 and Powergel A slurries showed comparable nitrogen losses to groundwater. The Powergel A losses were larger than for Nitrex 201, but considering the extreme variability of the data, the difference is probably not significant. For Nitrex 201, the nitrogen losses were particularly high in two holes where the mixing chamber and hose of the bulk mix truck were flushed into the hole at the end of the truckload. There is roughly 70 kg (~ 16 kg N) of explosives in the mixing chamber and hose, and the guar gum and crosslinker are shut off during flushing[72], leaving the nitrogen compounds susceptible to water attack. For Powergel A, the explosives in the mixing chamber/hose were flushed onto the ground, and thus did not contribute to the losses measured in the blastholes, but would become incorporated in the spoil, and be subject to leaching.

The average nitrogen content of the slurry loaded into the blastholes sampled was 341 kg N per hole, and thus the average loss of 4.2-6.8 kg N per hole represents a loss to groundwater of 1 to 2 percent of the nitrogen in the slurry. To put these losses in perspective, consider that 8900 t of slurry containing 2000 t of nitrogen were loaded at Fording Coal in 1979. A loss of 1 to 2 percent represents 20 to 40 t of nitrogen lost to groundwater, and ultimately to surface water. The nitrogen export from the mine in groundwater and surface water was estimated to be about 130 ty^{-1} N during 1979-80 (see section 3.5.4). Thus, it appears that losses to groundwater during loading wet blastholes with slurry could contribute significantly (15 to 30 percent) to nitrogen export from the mine.

3.4.7 OTHER CONTAMINANTS IN EXPLOSIVES

The basic ingredients in explosives used in surface mining were outlined in Section 2.1. Slurries also contain several other ingredients that are proprietary. The Ministry of Environment reviewed the ingredients contained in the explosives manufactured by CIL Inc. at Fording Coal, and determined that the only potential contaminants other than nitrogen compounds were aluminum, chromium and zinc. Aluminum was used in AN/FO (7% powdered aluminum) and slurries (0-16% paint grade aluminum or coarser) as a fuel-sensitizer. Sodium dichromate, $Na_2Cr_2O_7$, (~0.05%) was used as a jelling catalyst in slurries. Zinc nitrate (0.12%) was used in the Powergel slurries introduced in May 1980. The aluminum and chromium data for Fording Coal are discussed below, but post May 1980 zinc data had not been evaluated at the time of writing.

(a) Aluminum

Aluminum (elemental) is insoluble in water in the pH range of natural water, probably because of its aluminum oxide coat[5,14,100,101]. The reaction between ammonium nitrate and aluminum during detonation produces aluminum oxide (Al_2O_3), which is a very stable, inert and insoluble solid[3,4,5,14,100]. The occurrence of aluminum in surface water is limited since it is usually sorbed to sediments or precipitated from solution[100]. Soils have great capacities to precipitate soluble aluminum at pH values from about 5.5 to 8.0[39]. Consequently, it is expected that the aluminum used in explosives would not be a water quality concern in a non-acid environment such as exists at Fording Coal.

The aluminum monitoring data for Fording Coal is summarized in Table 36. To evaluate these data, consider the following effluent and water quality criteria:

- 0.5-1.0 mgL^{-1} dissolved aluminum is allowed in final effluents discharged to marine and fresh waters from the mining industry in B.C.[102].
- 0.1 mgL^{-1} (total extractable) aluminum limit was recommended to protect aquatic life and swimmers in fresh water[39,100,101].
- 1.-5 mgL^{-1} dissolved aluminum is acutely toxic to fish[39,101]
- aluminum has not been shown to be harmful to public health, and thus no drinking water guidelines have been formulated[100].

Table 36 shows that there were relatively high total aluminum levels in the CIL sump and in drill holes on the blasting pattern, but these waters were not discharged to surface water. The Al levels in the #7 spoil drainage, Eagle Pond, North tailing pond and CIL ditch were relatively low ($\leq$0.2 mgL^{-1}Al), meeting the most stringent effluent objective for the B.C. mining industry. Al in the Fording River was low ($\leq$0.02 mgL^{-1}Al) except for 2 samples taken on May 11, 1977, at sites 0200040 and 0200201, that had dissolved Al values of 0.07 mgL^{-1} and 0.5 mgL^{-1}, respectively. The latter value exceeded the recommended level to protect aquatic life.

The occurrence of 0.5 mgL^{-1} dissolved aluminum in the Fording River during freshet when the pH was 8.1 is puzzling because of the large flow available to dilute mine effluents, and the expected behaviour of aluminum in near-neutral waters. It may be that it is a spurious result, but further monitoring should be conducted to clarify the situation.

We recommend that pH, flow and dissolved and total aluminum be monitored in the Fording River and the major discharges to the river to assess the situation.

(b) Chromium

The chromium used in the explosives ($Na_2Cr_2O_7$) was present in the hexavalent (Cr (VI)) form. Cr (VI) is anionic and not strongly absorbed by soil or particulate matter[103], but is rapidly reduced to trivalent chromium (Cr (III)) in soils, which is strongly absorbed by soils[60]. Cr (VI) reacts strongly with oxidizable substances, usually organic molecules to form trivalent chromium (Cr (III)). Cr (VI) is stable under aerobic conditions if there is no organic matter present. Under anaerobic conditions it is reduced to Cr (III)[103]. Cr (III) precipitates as chromium oxide at neutral or slightly alkaline pH, and has a strong tendency to form stable complexes with organic and inorganic substances. It is very unlikely that much dissolved chromium will be present in water because Cr (III) is least soluble in the pH range covered by neutral waters[103].

The chromium monitoring data for Fording Coal are summarized in Table 37. The following effluent and water quality objectives have been recommended for chromium:

- 0.05-0.3 mgL^{-1} dissolved Cr is allowed in final effluents discharged to marine and fresh waters from the mining industry in B.C.[102].
- 0.05 mgL^{-1} Cr is the maximum acceptable concentration in drinking water[33].
- 0.02-0.04 mgL^{-1} total Cr to protect aquatic life[103].

Table 37 shows that there were high chromium levels in the CIL sump, but this effluent was discharged to the South tailing pond. The other mine effluents contained relatively low chromium levels, meeting the most stringent effluent objective for the B.C. mining industry. Cr in the Fording River downstream from Fording Coal was very low, with only one value in ten (9 μgL^{-1} total Cr) slightly above the detectable limit of 5. μgL^{-1}.

3.5 NITROGEN SOURCES

3.5.1 INTRODUCTION

The nitrogen sources at the Fording Coal mine were identified and quantified during five intensive sampling periods in 1979-80. The sampling periods were spaced throughout the year (August 14-16, 1979; October 23-25, 1979; February 26-28, 1980; April 14-17, 1980; and June 3-5, 1980) to obtain data from the various stages of the annual water cycle (see Figure 6). The flow and nitrogen concentration of mine drainage, effluents and receiving waters upstream, within and downstream from the mine were usually measured on 3 consecutive days during each sampling period. The locations of the sites sampled are shown in Figure 11. The methods used are outlined in Appendix A.

The flow, nitrogen concentration and nitrogen loading data for each nitrogen source are presented in Tables 4 to 30 (the tables are arranged in order from upstream to downstream). The tables also contain data collected by Fording Coal and the Ministry of Environment prior to the 1979-80 study period, but the utility of the earlier data is limited by the lack of flow data. Inorganic nitrogen (NH_3-N + NO_3-N + NO_2-N) balances for the mine for each of the 5 sampling periods are presented in Figures 12 to 16. The balances are expressed in terms of kgd^{-1} of inorganic nitrogen and are the average loadings for the sampling period.

To estimate the annual export of inorganic nitrogen from the mine in the Fording River for the period July 1979 - June 1980, water samples for nitrogen analysis were collected on a near daily frequency from one of three sites in the river (0200271, 0200316 or 0200311, depending on access conditions) at the downstream end of the mine. The river flows for nitrogen loading calculations were derived by extrapolation of flow data from Water Survey of Canada station 08NK021 (shown in Figure 11), and from flow measurements made by Fording Coal and the Ministry of Environment at sites 0200316 and 0200271. The flows, inorganic nitrogen concentrations, and inorganic nitrogen loadings in the Fording River downstream from the mine are presented in Figure 6.

3.5.2 MAJOR NITROGEN SOURCES

The annual export of inorganic nitrogen from the mine during July 1979 - June 1980 was estimated to be about 130 t N (see section 3.5.4). About 80 t N left the mine in the Fording River and about 50 t N entered the groundwater of the Fording River valley. The major nitrogen sources identified during the study were:

- Clode pit/spoil drainage to the river (~ 60 ty^{-1} N)
- South tailing pond seepage to groundwater (~ 50 ty^{-1} N from various sources, including ~ 15 ty^{-1} N from CIL swamp)
- CIL swamp drainage (~ 30 ty^{-1} N; 15 ty^{-1} to Fording River and 15 ty^{-1} to groundwater via the South tailing pond)
- Swift Creek to the river (~ 5 ty^{-1} N from South Greenhills pits/spoils)

(a) Clode Pit/Spoil Drainage

This was the largest source of inorganic nitrogen found during the study, contributing ~ 60 ty^{-1} N, or 45 percent of the estimated 130 t y^{-1} N entering the river and groundwater. It accounted for 60-100 percent of the nitrogen in the Fording River, depending on the season.

This source was comprised of four drainages entering the Clode and Eagle settling ponds from the Clode pit and spoil piles as shown in Figures 12 to 16. After entering the ponds, the nitrogen eventually reached the river via a combination of overflow from the ponds during spring snowmelt, and year-round seepage losses from the ponds. The seepage losses from the ponds were estimated by monitoring surface seepage flows and/or by measuring the differences in the loadings at river sites bracketing the ponds. The combined nitrogen loadings for the four drainages ranged from 130 kgd^{-1} N in winter to 670 kgd^{-1} N during spring snowmelt.

In order of importance, the four drainages from the Clode pit/spoil area were:

(i) #7 spoil drainage to Clode pond (site 0225078 or CC5).
This drainage emerged from the base of #7 spoil, and probably included infiltrating pit water from the Clode Pit. It accounted for 60-85 percent of the nitrogen from the Clode pit/spoil area. Nitrogen loadings from this source ranged from 77 kgd^{-1} N during winter to 500 kgd^{-1} N during spring snowmelt (Table 8).

(ii) #8 spoil drainage to Eagle pond (site 0225087).
This drainage emerged from the base of #8 spoil and accounted for 7-40 percent of the nitrogen from the Clode pit/spoil area. Loadings ranged from 31 to 81 kgd^{-1} N (Table 16).

(iii) Clode Creek diversion to Clode pond (site 0225092).
Clode Creek accounted for 0-10 percent of the nitrogen from the Clode pit/spoil area, with loadings of 0 to 70 kgd^{-1} N (Table 6). Nitrogen levels in Clode Creek above the mine were very low (Table 7 - site CC3, and Figures 12 to 16), and increased as the creek flowed through the Clode-Turnbull pit and spoil areas.

(iv) Eagle Creek to Eagle pond (site 0225079).

Eagle Creek accounted for 0 to 4 percent of the nitrogen (0 to 18 kgd^{-1} N) from the Clode pit/spoil area (Table 15).

Tables 6, 8, 15 and 16 show that most of the inorganic nitrogen (114 mgL^{-1} N, maximum) in the Clode pit/spoil drainages was in the form of nitrate (111 mgL^{-1} N, maximum), with smaller amounts of ammonia (3.7 mgL^{-1} N, maximum) and nitrite (0.75 mgL^{-1} N, maximum). The maximum nitrite value was measured by Fording Coal and may be artificially high. The maximum nitrite value measured in these drainages by the Ministry of Environment was 0.18 mgL^{-1} N, and there is evidence that Fording Coal data tend to overestimate nitrite levels (see section 3.6.5).

The maximum nitrite (0.18 mgL^{-1} N) and un-ionized ammonia (3.7 mgL^{-1} N total ammonia contains ~ 0.2 mgL^{-1} N un-ionized ammonia at pH 8.5 and water temperature of 10°C[8]) values were at or near the levels that are acutely toxic to rainbow trout (the 96 h LC_{50} for un-ionized ammonia or nitrite is approximately 0.2 mgL^{-1} N, see section 2.4.2). The maximum nitrate concentration was about one-tenth of levels that are acutely toxic to rainbow trout (section 2.4.2). As mentioned above, the Clode pit/spoil drainages passed through settling ponds before reaching the Fording River, and these ponds reduced ammonia and nitrite to below acutely toxic levels (Tables 9, 10, 11 and 18).

(b) South Tailing Pond Seepage

This was the second largest inorganic nitrogen source found during the study, contributing about 50 ty^{-1} N, or about 40 percent of the 130 ty^{-1} N estimated to be entering the river and groundwater. The South Tailing Pond seepage was entering the groundwater system, and did not appear to be reaching the river during the study period. The South Tailing Pond began receiving tailings effluent in April 1979, and it was discovered that about 0.2 m^3s^{-1} [79] was being lost via seepage to groundwater at the south end of the pond. Groundwater wells were installed at the south end of the pond and about 0.06 m^3s^{-1} [79,80] of seepage was pumped back into the pond.

The nitrogen losses from the pond of 100 to 180 kgd^{-1} N were calculated using the above flows, and the inorganic nitrogen concentrations in the tailing pond supernatant and recycled seepage (Tables 27 and 28). The nitrogen in the South Tailings Pond has several sources, including:

- nitrogen washed from raw coal in the wash plant (not measured)
- nitrogen in Greenhills pit water pumped either directly to the South Tailing Pond (not measured) or indirectly via the North Tailing Pond (2 to 71 kgd^{-1} N, Table 19) and the wash plant
- nitrogen in the CIL explosives plant sump effluent pumped to the pond (2 to 50 kgd^{-1} N, Table 24)
- nitrogen from the CIL swamp drainage (0 to 150 kgd^{-1} N, Table 26), roughly 15 ty^{-1} N
- nitrogen from Eagle Mountain drainage (Blake and Blaine Creeks, 0 to 18 kgd^{-1} N, Figures 12 to 16)

No attempt was made to conduct a nitrogen balance on the South Tailing Pond.

The seepage from the pond did not appear to be reaching the river during the study period. Monitoring conducted by Fording Coal during the winter of 1981-82 suggests that the seepage from the South Tailings Pond was reaching the Fording River just upstream from Swift Creek[97].

(c) CIL Swamp Drainage

About 30 ty^{-1} N came out of the CIL swamp during the study period, or roughly 25 percent of the total export from the mine. About 15 ty^{-1} N was discharged to the Fording River, and about 15 ty^{-1} N was discharged to the South Tailing Pond via diversion ditches and pumping. The 15

ty^{-1} N discharged to the river represented about 20 percent of the 80 ty^{-1} N exported from the mine in the river.

The total loadings from the CIL swamp ranged from 22 to 260 kgd^{-1} N (Table 26, Figures 12 to 16). The source of the nitrogen in the CIL swamp drainage is believed to be largely the past discharges from the CIL plant. Prior to May 30, 1979 all of the effluent from the CIL plant (in-plant and yard drainage) was discharged to the swamp south of the plant. Since May 30, 1979, the in-plant effluent has been discharged to the South Tailing Pond, while the yard drainage continues to flow into the swamp. During the study period, nitrogen entered the swamp from the North Loop settling pond (0 to 24 kgd^{-1} N, Table 23) and from CIL plant yard drainage (snowmelt, rain, and washdown). The CIL yard drainage was intermittent and diffuse, and could only be measured on 3 occasions (Table 25). Nitrogen concentrations were high (20-620 mgL^{-1} N), but flows were small (1-2 Ls^{-1}) and intermittent, and thus loadings were small.

The nitrogen entering the swamp during the study period appeared to be relatively small (10 percent or less) compared to the nitrogen leaving the swamp, although the data for the CIL yard drainage were poor. It is concluded that the nitrogen in the CIL swamp drainage was mostly due to past discharges from the CIL plant.

Table 26 shows that during the study period (August 1979 - June 1980) most of the inorganic nitrogen (6.4-42.4 mgL^{-1} N) in the CIL swamp drainage was in the nitrate form (4.5-33.4 mgL^{-1} N) with lesser amounts of ammonia (1.8-8.75 mgL^{-1} N total ammonia or 0.07-0.33 mgL^{-1} N un-ionized ammonia at pH 8.5 and T = 5°C) and nitrite (0.008-0.55 mgL^{-1} N). The higher un-ionized ammonia and nitrite values exceeded levels that are acutely toxic to rainbow trout (96 h LC_{50} for un-ionized ammonia or nitrite is approximately 0.2 mgL^{-1} N, see section 2.4.2). It should be noted that much higher nitrogen values (Table 26, up to 135 mgL^{-1} N total ammonia, 108 mgL^{-1} N nitrate and 1.86 mgL^{-1} N nitrite) were measured by Fording Coal prior to the diversion of the CIL in-plant effluent to the South Tailings Pond on May 30, 1979. Discharges from the CIL plant via the CIL swamp are believed to have been the cause of the relatively high ammonia levels (Figures 18 and 19) in the Fording River during 1977-78 (see section 3.6.4).

We recommend that the discharge from the CIL swamp be removed from the Fording River, and discharged to the South Tailings Pond, or disposed of in some other acceptable manner. During 1979-80, the CIL swamp discharge contained un-ionized ammonia and nitrite at levels that are toxic to fish, and although it did not cause harmful levels in the Fording River once mixing of the effluent and river water was complete (sections 3.6.4 and 3.6.5), it is probable that harmful levels existed in the mixing zone. We also recommend that measures be taken to control spills of nitrogen compounds at the CIL explosives plant.

(d) Swift Creek

Swift Creek discharged about 5 ty^{-1} N to the Fording River during the study period, or roughly 4 percent of the total export from the mine. The source of the nitrogen in Swift Creek was drainage from the South Greenhills pits and spoil piles (Figure 16). The nitrogen loading in Swift Creek ranged from zero in winter to 88 kgd^{-1} N during spring snowmelt (Table 30). The inorganic nitrogen concentrations in Swift Creek were relatively low (0-10 mgL^{-1} N, Table 30), and consisted mostly of nitrate. The monitoring record (Table 30) indicates that elevated nitrogen levels in Swift Creek first appeared in April 1979.

3.5.3 NITROGEN BALANCES

Inorganic nitrogen balances for the mine for each of the 5 sampling periods are presented in Figures 12 to 16.

The basic pattern of the 5 nitrogen balances was the same, but there was substantial variation in the magnitude of the nitrogen flux over the annual hydrologic cycle.

The nitrogen loadings in the Fording River upstream from the mine were always very low (<1 to <11 kgd^{-1} N). Other streams sampled upstream from the mine such as Clode Creek, Lake Mountain Creek, Swift Creek and the North Interceptor Ditch were also very low in nitrogen. The inflow from the Clode pit/spoil area via the Clode and Eagle ponds caused major increases in the nitrogen loadings in the Fording River. The increases ranged from about 90 kgd^{-1} N during the summer, fall and winter of 1979-80 to 520-660 kgd^{-1} N during spring snowmelt in April-June 1980.

The CIL swamp drainage increased Fording River nitrogen loadings by about 30 kgd^{-1} N in October 1979 and February 1980, and by about 260 kgd^{-1} N during freshet in June 1980. During August 1979 and April 1980 the CIL swamp drainage was totally diverted to the South Tailing Pond, while in February 1980, partial diversion occurred. A loss of flow, and thus a loss of nitrogen (33 to 55 kgd^{-1} N) from the Fording River channel to groundwater was measured between the CIL plant and Swift Creek during August and October 1979. This loss of flow probably also occurred during February 1980, but river ice conditions prevented its measurement.

Seepage losses from the South Tailing Pond contributed 100 to 180 kgd^{-1} N to groundwater at the south end of the tailing pond, but there was no indication that this nitrogen was reaching the Fording River during the study period. Swift Creek contributed 73-88 kgd^{-1} N to the Fording River during April-June 1980.

Total inorganic nitrogen export from the mine during the 5 intensive sampling periods ranged from 200 kgd^{-1} N (60 kgd^{-1} N in the Fording River and 140 kgd^{-1} N in groundwater) in August 1979 to 1200 kgd^{-1} N (1100 kgd^{-1} N in the Fording River and 100 kgd^{-1} N in groundwater) during June 1980.

3.5.4 ANNUAL NITROGEN EXPORT

The nitrogen loadings in the Fording River downstream from the mine for the one year period of July 1979 - June 1980 are shown in Figure 6. The annual inorganic nitrogen export in the river for this period was about 80 t N. The annual nitrogen loading in the river above the mine was less than 1 t N, and thus can be ignored. The 80 t N includes about 5 t N that was in groundwater adjacent to the river, because losses of flow and nitrogen from the river to groundwater were assumed to have remained in the river channel. The river loadings ranged from a low of 40 kgd^{-1} N during September 1979 to 1450 kgd^{-1} N in May 1980 during the spring runoff, with an annual average of 220 kgd^{-1} N. About 75 percent of the nitrogen export occurred during spring snowmelt in April, May and June.

In addition to the 80 ty^{-1} N in the river, an estimated 50 ty^{-1} N entered the groundwater system via seepage from the South Tailing Pond. (This value was calculated by averaging the daily seepage losses from the South Tailing Pond as shown in Figures 12 to 16 and muliplying by 365 days). Thus, the loss of inorganic nitrogen from the mine in the river and groundwater was about 130 ty^{-1} N. Other losses of inorganic nitrogen from the mine include the coal dryer stack emissions (a portion of this is deposited at the mine) and the product coal. Assuming that 3.0×10^6 ty^{-1} of product coal is dried from 20 percent moisture content to 8 percent, shipped at 8 percent moisture content, and that the average inorganic nitrogen

content of the water in the coal is 10 mgL^{-1} N or 0.01 kgm^{-3} N (average of North and South Tailing pond supernatant), then the inorganic nitrogen leaving the mine via these routes would be
6 ty^{-1} N (3.0 x 10^6 ty^{-1} x 1.0 m^3t^{-1} x 0.01 kgm^{-3} N x 0.20
= 6000 kgy^{-1} N = 6 ty^{-1} N).

A portion of the nitrogen in the dryer stack emission was probably deposited at the mine, and thus included in the nitrogen measured in drainage from the mine. For this reason, and because the 6 ty^{-1} is small compared to the 130 ty^{-1} exported from the mine, it will not be included in further calculations.

The export of 130 ty^{-1} of inorganic nitrogen represents 5 to 6 percent of the average annual explosives use at Fording Coal Ltd. as shown below for various averaging periods:

Averaging Period	Number of Years	Average Annual Explosives Use ty^{-1} N	Nitrogen Losses* %
mid 1979 - mid 1980	1 (study year)	2250	5.8
1979 - mid 1980	1.5	2300	5.7
1978 - mid 1980	2.5	2400	5.4
1977 - mid 1980	3.5	2700	4.8
1976 - mid 1980	4.5	2550	5.1
1975 - mid 1980	5.5	2600	5.0

* 130 t N expressed as a percentage of the average annual explosives use for the period.

Nagpal[81] concluded that nitrogen is probably leached from spoil at Fording Coal within one year, and thus it would be appropriate to use the shorter averaging periods in the above table, thus yielding a loss of about 6 percent. The other 94 percent of the nitrogen in the explosives used presumably entered the atmosphere as nitrogenous gases (N_2, N_2O, NO_2, NO, NH_3) during detonation.

3.5.5 NITROGEN CONTENT OF SPOIL

Nagpal[81] leached 13 samples of fine spoil from Fording Coal with water, and found that the average release of dissolved inorganic nitrogen was 16 g N bank m^{-3} of spoil. The inorganic nitrogen release from the total spoil (fine plus coarse) is probably less, because it is expected that coarse spoil contains less inorganic nitrogen than fine spoil. The inorganic nitrogen released from the fine spoil represented 8 percent of the average amount of inorganic nitrogen in the explosives used to blast one bank cubic metre of rock (i.e. 0.2 kg N bank m^{-3}). Nagpal[81] concluded that the inorganic nitrogen in fresh spoil at Fording Coal would probably be leached out within one year.

During 1979-80, about 11.25 x 10^6 bank m^3 of rock was blasted at Fording Coal using 2250 t N in explosives. If the spoil released 16 g N bank m^{-3} (6 g N t^{-1}) or 8 percent of the explosives nitrogen used, 180 ty^{-1} N would have leached from the spoil in 1979-80. The measured amount of inorganic nitrogen leached from the mine by surface and groundwater during 1979-80 was 130 ty^{-1} N. The main reason for this discrepancy is believed to be that the inorganic nitrogen release from fine spoil overestimates the release from the total spoil.

3.5.6 OTHER NITROGEN SOURCES

(a) Fertilizer

Fertilizer use at Fording Coal was examined to evaluate its potential for contributing nitrogen to the Fording River. The quantity of nitrogen contained in the fertilizer used in mine and exploration reclamation was 2.7 t N in 1978 and 1.8 t N in 1979. Fertilizer use prior to 1978 was lower than that in 1978-79. The nitrogen content of the explosives used at the mine in 1978 and 1979 was 2687 t N and 2231 t N, respectively, or 1000 to 1200 times greater than that contained in the fertilizer.

Nitrogen export from the mine in water during 1979-80 was estimated to be about 130 ty^{-1} N (section 3.5.4). If it is assumed that all of the 2.7 t of nitrogen used as fertilizer in 1978 was lost to water, it would have represented 2 percent of the nitrogen export. It is more probable that not more than 20 percent of the fertilizer nitrogen was lost to water[82], thus suggesting that the nitrogen export due to fertilizer would be less than 1 percent of the total export. We conclude that fertilizer use was not a significant contributor to nitrogen export from the mine during 1971-79.

(b) Domestic Sewage

Domestic sewage contains nitrogen, and thus the discharge of treated sewage effluent at Fording Coal may contribute nitrogen to the Fording River. Domestic sewage was given secondary treatment, and discharged to the North Loop settling pond inside the railway loop. The effluent from the North Loop pond infiltrated to ground until October 1979. In October 1979, the pond began to decant to the Fording River via the swamp south of the CIL plant.

The sewage treatment plant discharged an average of 455 m^3d^{-1} of effluent to the North Loop pond with an average inorganic nitrogen (NO_3-N + NO_2-N + NH_3-N) concentration of 6.8 mgL^{-1} N during the period July 1978 to February 1980. (Analyses of organic nitrogen in the effluent were not done). Thus, the sewage treatment plant discharged an average of 3.1 kgd^{-1} N or 1.1 ty^{-1} N. Using the conservative assumption that all of this nitrogen reached the river, it would represent less than one percent of the 130 ty^{-1} N exported from the mine in water. We conclude that domestic sewage was not a significant contributor to nitrogen export from the mine during 1971-80.

(c) Coal

Coal normally contains 1 to 2 percent nitrogen, that is present exclusively as organically bound nitrogen[83]. Organic nitrogen can be converted to ammonia through chemical and bacterial action under either aerobic or anaerobic conditions[7,63], and thus the potential exists for the release of water-soluble nitrogen from coal.

A flowing artesian well located upstream from the mine between the Clode pond and the powder magazine (see Figure 4) was sampled 9 times during 1979-80, and the data are summarized in Table 31. The well is 162 m deep and intersects 27 m of coal seams. The well water contained a nearly constant average of 4 mgL^{-1} NH_3-N. The source of the ammonia in the well water is believed to be from the decomposition of organic nitrogen in the coal seams, because surface water and shallow groundwater upstream from the mine were very low in nitrogen.

The water discharging from the coal seams in the highwalls of the Turnbull, Clode and Greenhills pits was sampled 9 times and the data are summarized in Table 32. These samples contained 1.6-14.8 mgL^{-1} of dissolved inorganic nitrogen, with an average of 6.6 mgL^{-1}. A problem with these samples is that it is difficult to guarantee that the water came directly from the coal seams and was not contaminated by residual explosives. The samples taken from the Clode pit highwall on June 5, 1980 are suspect in this regard because the water was cascading down the highwall, and it could not be determined if the water came from the coal seams, or from drainage above the highwall. The #1 spoil dump is located above this highwall, and thus residual explosives may have contaminated the samples.

The above suggests that water from coal seams at Fording Coal contains about 4 mgL^{-1} N of inorganic nitrogen. Estimating the contribution that the nitrogen from the coal seams made to the nitrogen export from the mine is difficult, because the quantity of coal seam water is not known. A crude estimate can be made for the Clode pit/spoil area, under winter conditions using the results obtained during February 26-28, 1980, if we assume that all of the seepage from the Clode pit/spoil area originated from the coal seams. The average nitrogen content of the Clode pit/spoil seepage was about 100 mgL^{-1} N, and if we assume a coal seam water nitrogen content of about 4 mgL^{-1} N, then the contribution of the coal seams to the nitrogen leaving the Clode pit/spoil area was 4 percent during winter. This estimate is conservative because it is probable that not all of the seepage originated from the coal seams. The 4 percent contribution during winter is probably a maximum, because during the rest of the year, the coal seam water flow and nitrogen loading would probably remain relatively constant, while other water flows and nitrogen loadings from the pit and spoil would increase dramatically (see section 3.5.3).

Inorganic nitrogen may also be released from the leaching of the coal exposed in the pits, spoil piles and tailings ponds at the mine. To estimate the amount of inorganic nitrogen that can be leached from coal that has not been contaminated by explosives, Nagpal[81] leached coal samples from diamond drillholes with water. The coal released an average of 1 g of soluble inorganic nitrogen per tonne of coal. Spoil samples leached with water released 6 times more inorganic nitrogen than did the coal samples (section 3.5.5). If we assume that 5×10^6 t of freshly mined coal is leached with water per year at the mine, and that it yields 1 g N t^{-1}, then 5 ty^{-1} N would be leached from the coal. This would represent about 4 percent of the 130 ty^{-1} N exported from the mine in 1979-80.

We conclude that coal may have contributed roughly 4 to 8 percent of the inorganic nitrogen exported from the mine in 1979-80.

3.6 WATER QUALITY EFFECTS

3.6.1 INTRODUCTION

The nitrate, total ammonia, un-ionized ammonia and nitrite concentrations in the Fording River at the Fording Coal mine for 1973 to mid 1980 are summarized in Figures 17, 18, 19 and 20. The dissolved inorganic nitrogen (NO_3^-N + NO_2^-N + NH_3^-N) concentrations in the Fording River downstream from the mine for the period, July 1979 to June 1980, are displayed in Figure 6.

3.6.2 PATTERNS

Nitrogen monitoring in the Fording River at the mine began in January 1973 (mining began in 1971), and the nitrogen concentrations were very low during 1973. Occasional elevated nitrogen levels appeared during 1974-75, and the first high nitrogen levels appeared during low flows in late 1976. Nitrogen levels remained high during low flows from 1976 to mid 1980. There is a striking correlation between the appearance of high nitrogen levels in late 1976 (after six years of mining) and the switch from AN/FO to slurry explosives in 1975-76 (Figure 7) due to increasingly wet ground conditions in the pits.

The annual pattern of inorganic nitrogen concentrations in the Fording River at Fording Coal is illustrated in Figure 6 and also in Figures 17, 18, 19 and 20. Minimum concentrations occurred during spring snowmelt, and then increased gradually as river flows declined, reaching maximum concentrations during winter low flows. The occurrence of maximum concentrations during the winter when biological activity is at a minimum probably tends to minimize the effects of the nitrogen on aquatic life. The effects on aquatic life in areas of the province where low flows occur during the summer would tend to be more severe.

Nitrogen loadings in the river (Figure 6) were lowest and relatively constant during July 1979 through March 1980, with concentrations increasing by one order of magnitude (1 to 10 mgL^{-1} N), and flows declining by a similar amount (1 to 0.1 m^3s^{-1} N). Maximum loadings occurred during freshet when concentrations declined by one order of magnitude (10 to 1 mgL^{-1} N), but flows increased by two orders of magnitude (0.1 to 10 m^3s^{-1}).

Nitrogen concentrations in the Fording River peaked immediately downstream from Fording Coal, and declined with distance downstream from the mine due to dilution by inflows of low nitrate water. This pattern is illustrated in Table 33. A similar pattern was documented by B.C. Coal Ltd.

and B.C. Research in their water quality studies for the Greenhills Coal Project on the Fording River downstream from Fording Coal[43]. Based on drainage areas, it is expected that nitrate levels 16 km downstream from Fording Coal (at the Greenhills Coal Project) and at the mouth of the Fording river would be roughly one-quarter and one-sixth, respectively, of the levels immediately downstream from the mine.

Crozier and McDonald[84] documented that nitrate concentrations in the Elk River downstream from the Fording River have been increasing since 1975. They attributed this increase largely to explosives residuals from coal mining operations, primarily Fording Coal Ltd. The increase was greatest in the Elk River just downstream from the Fording River, where peak concentrations increased from less than 0.2 mgL^{-1} NO_3-N to 0.5 mgL^{-1} NO_3-N during winter low flow. This increased concentration is well below levels that are toxic to humans or aquatic life, but it would provide ample nitrogen for algal growth if all of the other requirements for algal growth (e.g. light, phosphorus, substrate, etc.) were met.

The effect of nitrate, ammonia and nitrite on water quality in the Fording River is evaluated in the following sections using the water quality criteria presented in section 2.4.

3.6.3 NITRATE

Nitrate was the major inorganic nitrogen species emanating from the mine. Nitrate concentrations in the Fording River upstream from the mine ranged from less than 0.02 to 0.3 mgL^{-1} N, while concentrations downstream ranged from 0.3 mgL^{-1} N during freshet to 10.8 mgL^{-1} N during winter low flows (Figure 17).

Nitrate slightly exceeded the maximum acceptable concentration for drinking water of 10 mgL^{-1} N during low flows in November 1976 and February-March 1980. Consequently, there may be a health hazard if infants under the age of 6 months were fed river water from within or immediately downstream from the mine during low flows. There are no licenced drinking water users on the Fording River downstream from Fording Coal at present, but campers that frequent the area may be using the river for drinking water.

Nitrate also slightly exceeded the preferred concentration for rainbow trout recommended by Westin[46] of 6 mgL^{-1} N during the winters of 1976-77, 1977-78 and 1979-80, but was well below the recommended maximum allowable concentration of 56 mgL^{-1} N. Considering the conservatism of the preferred concentration (i.e. it is 0.01 of 7d LC_{10}), it is unlikely that the nitrate levels in the Fording River had any effect on fish.

Nitrate exceeded the guideline level for preventing eutrophication in free-flowing waters of 1.0 mgL^{-1} NO_3-N during most of the year in the years 1977 through 1980. Nordin[85] found, however, that phosphorus was the limiting nutrient for algal growth in the Fording River, and that the low phosphorus levels in the river prevented excessive algal growth despite the high nitrate levels. Increases in phosphorus in the river would most probably cause excessive algal growth.

To protect human health it is recommended that nitrate plus nitrite levels in the Fording River not exceed 10 mgL^{-1} N, based on the maximum acceptable concentration for drinking water (see section 2.4.1 (a)). Aquatic life would be well protected from the toxic effects of nitrate by this level (see section 2.4.2 (b)). To prevent excessive algal growth, it is recommended that phosphorus discharge to the river be prohibited.

3.6.3 AMMONIA

Total ammonia (NH_4^+-N plus NH_3-N) data for the Fording River at Fording Coal are presented in Figure 18. Un-ionized ammonia (NH_3-N) values calculated from total ammonia, pH and water temperature data using Table 2 of Trussell[8] are presented in Figure 19.

Total and un-ionized ammonia levels upstream from the mine were very low during 1973-80, not exceeding 0.1 mgL^{-1} N and 7.5 μgL^{-1} N, respectively. Downstream from the mine, ammonia levels were low until the winter of 1977-78 when values of up to 5.0 mgL^{-1} N total ammonia and 100 μgL^{-1} N un-ionzed ammonia were measured. Since 1978, ammonia downstream from the mine has declined to moderate levels. The high ammonia levels in 1977-78 are believed to be due to discharges from the CIL explosives plant. Ammonia in drainage from the CIL plant was only measured once during the winter of 1977, but gave a value of 135 mgL^{-1} N (Table 26). The relatively high concentrations of both ammonia and nitrate in the CIL drainage indicate that they were caused by the recent addition of ammonium nitrate (NH_4NO_3) to water, which probably occurred because of spills at the explosives plant. Ammonia discharges from the explosives plant have been reduced since 1978 (Table 26).

Total ammonia greatly exceeded the former acceptable limit for drinking water of 0.5 mgL^{-1} N during the winter of 1977-78, but remained at or below the limit during 1978-80. The high total ammonia would probably have caused operational problems in a water treatment plant as outlined in section 2.4.1(b). There are no licenced drinking water users on the Fording River downstream from the mine at the present time.

The high un-ionized ammonia levels during 1977-78 (25-100 μgL^{-1} N) were below the concentrations found to be acutely toxic to trout by most researchers (i.e. ~ 200 μgL^{-1} N), but were above the concentrations found to cause sublethal effects (3-25 μgL^{-1} N) in trout. Consequently, it is possible that trout in the Fording River may have suffered sublethal effects such as gill damage and reduced growth rates during the 6 month period from November 1977 to April 1978. Since 1978, un-ionized ammonia has ranged up to 14 μgL^{-1} N for short periods of time, and although this is within the 3-25 μgL^{-1} N range reported to cause sublethal effects during continuous exposure, the intermittent nature of the exposure would preclude effects on trout.

To protect aquatic life, it is recommended that un-ionized ammonia in the Fording River not exceed 7 μgL^{-1} N for prolonged periods (e.g. more than 10 days), based on the B.C. Research[49] guidelines for the maximum acceptable concentration for continuous exposure (see section 2.4.2 (d)). Un-ionized ammonia should not exceed 30 μgL^{-1} N at any time. This value was derived by multiplying the lowest acute toxicity value for rainbow trout (60 $\mu gL^{-1}NH_3$-N) by the ratio of the maximum value causing no mortality after 36 days (180 $\mu gL^{-1}NH_3$-N) and the lowest acute toxicity value for cutthroat trout fry (400 $\mu gL^{-1}NH_3$-N) (see section 2.4.2 (d)). This would also provide protection for any future domestic water users on the Fording River because total ammonia concentrations would have to be less than about 0.5 mgL^{-1} N to meet the criteria for un-ionized ammonia at the pH and temperature of the Fording River.

3.6.5 NITRITE

Figure 20 shows that nitrite levels upstream from Fording Coal were very low during 1973-80, not exceeding 10 μgL^{-1} N. Downstream from the mine, nitrite was generally low until late 1976, and then values of up to 300 μgL^{-1} N were measured during low flows between 1976 and 1980.

It should be noted in Figure 20 that the Fording Coal nitrite values were consistently higher than those of the Ministry of Environment on occasions when they both sampled at approximately the same time. Split samples of 3 effluents analyzed by Fording Coal and the Ministry of Environment (Table 34) showed that Fording Coal's nitrite results were an order of magnitude or more greater than the Ministry's for 2 of 3 samples. The cause of the difference was probably sample preservation and handling techniques. Ministry of Environment samples were frozen on the day of sampling and remained frozen until thawed for analysis in the laboratory, whereas the Fording Coal samples were shipped to the laboratory at ambient temperatures without preservation. Table 34 suggests that nitrification occurred in the Fording samples, causing a shift from NH_3-N to NO_2-N and NO_3-N. NH_3-N may also have been lost through volatilization from warm, alkaline samples.

The Fording Coal data suggest that nitrite reached levels acutely toxic to trout (i.e. 60-300 μgL^{-1} N) on several occasions during low flows in 1977-80. Nitrite frequently exceeded the threshold level for sublethal effects (20 μgL^{-1} N) during that period. On the other hand, the Ministry of Environment data suggest that acutely toxic levels were never reached, and that the sublethal threshold has not been exceeded since 1976. The Ministry monitored nitrite in the river almost daily during 1979-80, and did not find any values that exceeded the sublethal threshold of 20 μgL^{-1} N, but Fording Coal reported values of up to 150 μgL^{-1} N for the same period. Considering the sample preservation and handling methods used by Fording Coal, the Ministry of Environment's data probably represent the actual nitrite levels in the Fording River.

To protect aquatic life, it is recommended that nitrite concentrations in the Fording River not exceed 20 μgL^{-1} N for prolonged periods (i.e. ~ 10 days), based on the B.C. Research[49] guideline for the maximum acceptable concentration for continuous exposure (see section 2.4.2 (c)). Nitrite concentrations should not exceed 60 μgL^{-1} N at any time, because this was the maximum level with no mortality after 10 days (see section 2.4.2 (c)). This would also provide ample protection for any future domestic water users, because the maximum acceptable concentration for nitrite in drinking water is 1 mgL^{-1} N (i.e. 1000 μgL^{-1} N).

3.6.6 FORDING RIVER FISHERY

Lister *et al*[86] conducted a study of the fish populations in the Fording River at Fording Coal during the summer and fall of 1979. The study covered the Fording River from Henretta Creek to about 4 km downstream from Kilmarnock Creek, and indicated that there was a good population of Yellow stone cutthroat trout (Salmo clarki lewisi) in this portion of the river. Yellowstone cutthroat trout was the only species of fish encountered. About 4000 fish were captured and 180 spawners were observed during the study.

The results of the fisheries study tend to support the conclusion of the water quality evaluation that conditions that were acutely toxic to fish have not occurred in the Fording River at Fording Coal. Conditions that could cause sublethal effects on fish probably occurred in the river at times, but these subtle effects could not likely be detected by the fisheries study.

3.6.7 MONITORING

Continuing nitrogen monitoring is recommended at Fording Coal to ensure that the water quality objectives recommended in section 3.6.3, 3.6.4 and 3.6.5 are met. The monitoring program should include: regular monitoring of a site on the Fording River just downstream from the mine to determine if the water quality objectives are being met; and regular monitoring of the major nitrogen sources at the mine so that current knowledge of the sources is available to facilitate any necessary control measures.

The nitrogen situation at Fording Coal will change as mining changes, and indeed has changed since our 1979-80 study. Consequently, the monitoring program must be flexible, and thus a detailed program will not be specified. Monitoring should include nitrate, nitrite, ammonia, pH, temperature and flow for the Fording River and the major nitrogen sources. A minimum sampling frequency of monthly is recommended, but special circumstances and experience may call for more or less frequent monitoring. Attention must be paid to sample preservation and handling to ensure that results are accurate. The minimum detectable limits of the analytical techniques used must be well below recommended water quality objectives. The following minimum detectable limits are recommended:

nitrate: 20 μgL^{-1} N
nitrite: 5 μgL^{-1} N
total ammonia: 10 μgL^{-1} N

Visual surveillance of algal growth in the Fording River should be maintained.

3.7 CONCLUSIONS AND RECOMMENDATIONS FOR FORDING COAL

3.7.1 EXPLOSIVES USE

- Explosives use began in 1971 and an average of 10 000 ty^{-1} of explosives containing 2500 ty^{-1} of nitrogen were used at Fording Coal during 1976-80.

- The average powder factor or blasting ratio for 1971 through 1979 was 0.8 kg of explosives per bank m^3 of rock blasted. Considering the nitrogen content of the explosives, an average of 0.2 kg of nitrogen per bank m^3 was used.

- Slurry explosives were used almost exclusively during 1976-80 because of the wet conditions in the pits.

3.7.2 NITROGEN LOSSES

- About 130 ty^{-1} of nitrogen left the mine, partly in the Fording River (80 ty^{-1} N), and partly in groundwater (50 ty^{-1} N) during 1979-80. This loss was equivalent to 6 percent of the nitrogen in the explosives used. The other 94 percent of the nitrogen in the explosives used presumably entered the atmosphere as nitrogenous gases during detonation.

- Most of the nitrogen (~ 95%) discharged from the mine was derived from the nitrogen used in explosives.

- Other nitrogen sources included:
  - Fertilizer use: < 1%
  - Domestic sewage: <1%
  - Coal: ≈ 4-8%

- The major sources of nitrogen in water were:

Clode pit/spoil drainage:	~ 60 ty^{-1} N	(to river)
Miscellaneous sources*:	~ 35 ty^{-1} N	(to groundwater via South tailing pond)
CIL swamp drainage:	~ 30 ty^{-1} N	(15 ty^{-1} to river, and 15 ty^{-1} to South tailing pond)
South Greenhills pit/spoil drainage: (Swift Creek)	~ 5 ty^{-1} N	(to river)

- **The CIL swamp drainage contained ammonia and nitrite at levels that are toxic to fish, and the discharge of this drainage to the river should be terminated.**

- Spoil contained six times more soluble nitrogen than coal.

- The soluble nitrogen in fresh spoil is expected to be leached out within one year at the Fording Coal mine.

- Increased nitrogen losses from the mine appeared to be correlated with increased use of slurry explosives due to increasingly wet blasting conditions at the mine.

- About 1 to 2 percent of the nitrogen in explosives is lost when loading wet blastholes with slurry explosives. This may account for 15-30 percent of the nitrogen export from the mine.

* Mainly Greenhills pit water, wash plant effluent, and explosives plant effluent discharged to South tailing pond.

3.7.3 WATER QUALITY EFFECTS

- High nitrogen concentrations in the Fording River first appeared during low flows in late 1976, and concentrations have remained high during low flows through 1980. The appearance of high nitrogen concentrations coincided with the increased use of slurry explosives in 1975-76 due to wet blasting conditions.

- The nitrogen discharged from the mine was mainly nitrate, with relatively small amounts of more toxic ammonia and nitrite.

- Nitrate slightly exceeded the maximum acceptable concentration for drinking water on occasion during low river flows, within or immediately downstream from the mine.

- Total ammonia greatly exceeded the acceptable limit for drinking water, and un-ionized ammonia exceeded levels known to cause sublethal effects on trout, during low winter flows in 1977-78. The source of the ammonia is believed to have been the CIL explosives plant effluent.

- Nitrite was below the threshold level for sublethal effects on trout, except during late 1976.

- Ample nitrogen was available in the river for algal growth, but growth was limited by low phosphorus levels.

- **To protect water quality in the Fording River for aquatic life, recreation and drinking, the following water quality objectives were recommended:**
  - **nitrate plus nitrite not to exceed 10 mgL^{-1} N**
  - **un-ionized ammonia not to exceed 7 μgL^{-1} N for prolonged periods (more than 10 days), and not to exceed 30 μgL^{-1} N at any time**

- nitrite not to exceed 20 μgL^{-1} N for prolonged periods (more than 10 days), and not to exceed 60 μgL^{-1} N at any time
- prohibit phosphorus discharge to the river

- The above water quality objectives were essentially being met in the Fording River at Fording Coal during 1979-80.

- Continued nitrogen monitoring at the mine is recommended to ensure that these water quality objectives are met, that current knowledge on nitrogen sources is available, and that any necessary control measures can be implemented.

- Mine expansion plans should be assessed to predict impacts due to nitrogen, and appropriate nitrogen management techniques should be implemented (as outlined in section 5) to ensure that water quality objectives are met.

- Additional aluminum monitoring should be conducted as outlined in section 3.4.7 (a).

4. ELK RIVER BASIN COAL MINES

4.1 INTRODUCTION

Approximately 10.5×10^6 ty^{-1} of product coal was produced (mostly by surface mining) in the Elk River basin in 1979 by 4 mines[87]:

	ty^{-1}
Kaiser Resources Ltd. (now B.C. Coal Ltd.)	6.3×10^6
Fording Coal Ltd.	3.0×10^6
Byron Creek Collieries Ltd.	0.8×10^6
Coleman Collieries Ltd. (closed in 1980)	0.4×10^6
	10.5×10^6

Surface coal mining is expected to double in the future with the development of the following coal projects:

	ty^{-1}
Fording Coal Ltd. expansion[88] (under construction)	3.5×10^6
Greenhills Coal Project[43] (B.C. Coal, under construction)	1.8×10^6
Line Creek Coal Project[89] (Crows Nest Resources Ltd., under construction)	2.7×10^6
Byron Creek Colliers expansion[95]	1.2×10^6
Elk River Coal Project (Elco Mining Ltd.)[90]	4.0×10^6
	13.2×10^6 (product coal)

In view of the substantial present and projected surface coal mining in the Elk River basin, the relationship between explosives use and nitrogen levels in the basin was briefly examined.

4.2 EXPLOSIVES AND FERTILIZER USE

Large-scale surface coal mining was begun in the Elk River basin in 1969 by Kaiser Resources Ltd. (now B.C. Coal), and followed by Fording Coal Ltd. in 1971 and Byron Creek Collieries Ltd. in 1976. The use of explosives has increased accordingly from 2000 t (700 t N) in 1969 to 26 300 t (8000 t N) in 1979 as shown in Figures 21 and 22. Approximately 225 000 t (64 000 t N) of explosives was used in the 11 year period, 1969-1979. Kaiser Resources was the major explosives user (~ 65 percent), followed by Fording Coal (~ 35 percent) and Byron Creek Collieries (<1 percent). (Data were not obtained for Coleman Collieries, but explosives use in the B.C. portion of the mine was expected to be less than that used by Byron Creek Collieries, and thus was not significant).

Data for fertilizer use (for reclamation) were obtained for Kaiser Resources and Fording Coal. (Fertilizer use at Byron Creek and Coleman Collieries was judged to be negligible in comparison). Kaiser Resources used 14.4 t N as fertilizer during 1970-1979, inclusive, compared to an explosives use of 44 200 t N for the same period. Similarly, Fording Coal used 4.5 t N as fertilizer in 1978-79, compared to an explosives use of 4900 t N.

Explosives N use was thus ~ 1000 times greater than fertilizer N use. Assuming that losses of explosives N are about 1 to 10 percent of explosives N used, then explosives N losses are ~ 10 to 100 times as great as fertilizer N use. Fertilizer N losses could be on the order of up to 50 percent of fertilizer N used. We conclude that N losses from fertilizer have probably been negligible compared to N losses from explosives during 1969-79.

4.3 FUTURE EXPLOSIVES USE

The annual average amount of nitrogen in explosives that will be used at the proposed surface coal mines in the Elk basin has been estimated as follows:

	ty^{-1} N
Fording Coal Ltd. expansion	3000
Greenhills Coal Project	2100
Line Creek Coal Project	3000
Elk River Coal Project	4200
	12 300

The nitrogen content of explosives used in 1979 in the Elk basin was about 8000 t N, and thus it can be seen that the proposed coal projects could more than double the nitrogen used in explosives.

4.4 NITROGEN LEVELS IN RECEIVING WATERS

4.4.1 FORDING COAL

The nitrogen levels in the Fording River at Fording Coal are discussed in detail in section 3.6. Crozier and McDonald[84] documented that nitrate concentrations in the Elk River downstream from the Fording River have been increasing since 1975. They attributed this increase largely to explosives residuals from coal mining operations, primarily Fording Coal. Maximum Elk River nitrate concentrations were measured just downstream from the Fording River (upstream from B.C. Coal), and then declined in the downstream direction. Peak concentrations in the Elk River just downstream from the Fording River increased from less than 0.2 mgL^{-1} NO_3-N to 0.5 mgL^{-1} NO_3-N during winter low flows. The increased nitrate levels are well below concentrations that are harmful to humans or aquatic life (see section 2.4). They do increase the nitrogen that would be available for algal growth. Increased algal growth could occur if other factors such as phosphorus, light, substrate, etc. are favourable for algal growth.

4.4.2 B.C. COAL

Grave Creek and its tributary, Harmer Creek, are main drainage streams for B.C. Coal's surface mines on Harmer Ridge. The available nitrogen data for these streams are summarized in Table 35. The data show that there have been elevated nitrate levels (0.4-1.9 mgL^{-1} N) in these streams during 1975-80. Daily loadings of dissolved inorganic nitrogen ranged from 15 to 270 kgd^{-1} N. The substantial dilution available for Grave/Harmer Creeks in the Elk River (~ 22:1, minimum dilution ratio) has prevented any noticeable increase in nitrate in the Elk River from upstream to downstream from Grave Creek.

Recent information indicates that some of the other creeks draining B.C. Coal's operations also contain elevated nitrate levels:

Bodie (Baldy) Creek:	6.1-18.7 mgL^{-1} NO_3-N[91]
Erickson Creek:	2.9-5.1 mgL^{-1} NO_3-N[91]
Otto Creek:	0.05-3.4 mgL^{-1} NO_3-N[92]

The dilution available for these creeks in Michel Creek and the Elk River is large, and thus increases in nitrate in Michel Creek and the Elk River are not expected, given the nitrate levels measured to-date. Ammonia and nitrite levels at B.C. Coal have not been measured.

4.5 FUTURE NITROGEN LEVELS IN RECEIVING WATERS

The projected increase in explosives use in the Elk Basin suggests that there is potential for increased nitrogen levels in the basin. The extent to which this will occur cannot be predicted at this time, because the amount and type of nitrogen that will be discharged from any one mine depends on site specific factors that have yet to be assessed.

In general terms, it is expected that nitrogen problems could be experienced at the Elk River and Line Creek Coal Projects because their projected explosives use and the dilution available in their receiving waters is similar to that at Fording Coal. The Elk River Coal Project may be a particular problem because of its wet blasting conditions due to its valley bottom location. The Greenhills Coal Project is not expected to be a problem, because of the mostly dry blasting conditions (mountain top location), the availability of a water-tight tailing pond for recycle, the relatively long retention time/flow path for explosives-contaminated drainage, and the dilution available in the Fording River. Greenhills will probably make a relatively small addition to nitrate levels in the Fording River that have already been elevated by Fording Coal (see section 3.6). The Fording Coal expansion will entail an increase in explosives use, and has the potential to worsen the nitrogen situation at the mine if explosives use is not carefully managed.

At worst, nitrogen concentrations that are harmful (toxic) to humans or aquatic life could occur in the immediate vicinity of the proposed mines. Nitrification and dilution should limit the downstream extent of harmful levels. Nitrate levels will probably continue to increase in the Fording and Elk Rivers as mining expands, but should remain well below toxic levels. Increased nitrate will provide more nitrogen for algal growth, but if phosphorus continues to be the nutrient limiting algal growth, then no additional growth will occur. Crozier and McDonald[84] recommended that phosphorus discharge to the Elk basin be restricted because of the potential for excessive algal growth.

We recommend that assessments of the type outlined in the following section 5 be conducted for each new mine or expansion in the Elk basin.

5. PREDICTION AND MANAGEMENT OF IMPACTS

5.1 PREDICTION OF IMPACTS

5.1.1 INTRODUCTION

The use of nitrogen-based explosives in surface mining has the potential, under certain circumstances, to impair water quality for drinking, aquatic life and recreation due to the toxicity of nitrate, nitrite and ammonia, and their role in promoting algal growth.

This section outlines a procedure that can be used to evaluate and predict the impacts of nitrogen losses from explosives at proposed mines. This evaluation should be done as a part of the environmental studies under the Guidelines For Coal Development[93] and the Procedures For Obtaining Approval of Metal Mine Development[94]. The recommended procedure is outlined below, and includes several items that would normally be done for any impact assessment.

5.1.2 PROCEDURE

(a) Monitoring

Monitor surface and groundwater that is likely to be affected by the mine to determine the existing levels of parameters that may be affected by nitrogen losses. The purpose of this monitoring is:

- to document existing conditions prior to development
- to predict the impacts of increased nitrogen on water quality and algal growth
- to assist in the development of site-specific water quality objectives

Parameters:

Surface Water	Groundwater	Rationale	Minimum Detectable Concentration $\mu g L^{-1}$
nitrate	nitrate	derived from	20
nitrite	nitrite	explosives	5
ammonia	ammonia		10
pH	pH	for calculation	-
temperature	temperature	of un-ionized ammonia	-
phosphorus, total dissolved	phosphorus, total dissolved	for algal growth	3
phosphorus, dissolved ortho-phosphate	phosphorus, dissolved ortho-phosphate	predictions	3
turbidity	-	light conditions for algal growth	-
algal biomass	-	existing level of	-
chlorophyll a	-	algal growth	-
N:P ratio in algal tissue	-	assessment of algal response to increased N or P	-

Frequency: Monitoring should be conducted throughout the annual water cycle to document the full range of the parameters. The recommended basic program is: 4 times for groundwater and 6 to 8 times for surface water. Abnormal or highly variable results, or significant predicted impacts may call for additional monitoring.

Sites: Groundwater - sufficient wells and springs in proposed pits to obtain results representative of groundwater to be encountered during mining.

Surface water - sites upstream and downstream from proposed mining area.

The above information will allow the prediction of the probable effect of increased nitrogen or phosphorus on algal growth. If increased algal growth is predicted, and/or it is important to assess potential algal growth more accurately, then additional monitoring such as in situ growth experiments could be conducted[85].

(b) Water Uses

Determine the existing and potential uses of surface and ground water likely to be affected by the mine. Important uses that may be affected by increased nitrogen are:

- drinking water (nitrate/nitrite toxicity to infants)
- fisheries (nitrite and ammonia toxicity, and increased algal growth)
  - determine species present, numbers and importance
  - determine spawning, rearing and overwintering areas
- recreation/aesthetics (nitrite and ammonia toxicity to fish, and increased algal growth)
- industrial (i.e. industries sensitive to nitrogen such as food-processing)

(c) Flows and Dilution

Determine minimum flows and dilution available in the receiving waters throughout the year for nitrogen losses from the mine.

(d) Explosives Use

Estimate the annual explosives use over the life of the mine and the nitrogen content of the explosives. Explosives use can be estimated from the projected quantities of rock to be blasted each year (bank m^3) multiplied by an assumed powder factor (kg of explosives bank m^{-3} of rock blasted). The nitrogen content of explosives ranges from 20 to 33 percent, depending on the formulation (see section 2.1 and 3.4.4). These values can be used to calculate the annual weight of nitrogen in the explosives used. An estimate of the relative amounts of AN/FO and Al/AN/FO versus slurry explosives (i.e. relative amounts of blasting under dry versus wet conditions) should be made based on the expected groundwater conditions in the proposed pits.

(e) Nitrogen Losses

Predicting nitrogen losses to receiving waters from explosives use at proposed mines is a difficult task. The nitrogen losses will vary substantially depending on such site specific factors as climate, mine hydrology, groundwater conditions in the pits, and the degree to which recycling of water is practiced. Little quantitative information is available on nitrogen losses from mines.

The study at Fording Coal Ltd. indicates that about 6 percent of the nitrogen used in exposives at the mine was entering surface and groundwater (section 3.5.4). The conditions at Fording Coal probably gave it a relatively high percentage of nitrogen loss from explosives compared to other mines in the province. The ground that was blasted at Fording Coal was very wet (slurries were used almost exclusively for blasting), thus maximizing nitrogen losses to water. There is a moisture surplus (precipitation exceeds evapotranspiration) at the mine, which provides excess water to leach nitrogen from spoil. Finally, the water system was only partly closed, with several mine drainages discharging to receiving waters.

The information available for Brenda Mines Ltd. (see section 2.3.2) suggests that about 1 percent of the nitrogen used in explosives was lost to surface water. The ground blasted at Brenda Mines was relatively dry (mostly AN/FO was used), and there is a moisture deficit at the mine (evapotranspiration exceeds precipitation).

The Fording and Brenda experiences suggest that the range of nitrogen losses may be 1 to 6 percent, depending on the site specific circumstances. It is recommended that an initial nitrogen loss factor be calculated assuma 1 percent loss of nitrogen from AN/FO and a 6 percent loss from slurry. A comparison of the climate (e.g. moisture surplus or deficit) and degree of recycling at a proposed mine with those at Fording Coal and Brenda Mines will provide some further guidance in selecting an appropriate nitrogen loss factor.

The nitrogen loss factor is then multiplied by the annual quantities of nitrogen expected to be used in AN/FO and slurry explosives to calculate an annual nitrogen loading to the receiving waters. The nitrogen loading should then be distributed over the year, with the largest loadings occurring during spring snowmelt in the interior, and during winter rains on the coast. For example, at Fording Coal, nitrogen loadings during spring snowmelt were 2 to 4 times the annual average, while loadings during low flows were 0.6 to 0.9 of the annual average. A similar pattern was observed at Brenda Mines[15]. The seasonal nitrogen loadings and receiving water flows can then be used to calculate receiving water nitrogen concentrations.

The nitrogen lost to receiving water can be assumed to be virtually all nitrate, with small amounts of ammonia and nitrite, provided that explosives-contaminated drainage has been detained long enough for nitrification to occur. At Fording Coal, effluent from spoil piles and settling ponds typically showed 95 percent nitrification, with a minimum of 85 percent nitrification. Only explosives plant effluent, which had a relatively short time between its initial contamination and its discharge to the receiving waters, contained significant concentrations of ammonia and nitrate. The toxicity of ammonia and nitrite to aquatic life will normally make control of their discharge mandatory.

(f) Phosphorus Control

Consideration should be given to evaluating phosphorus losses from the mine to surface water because phosphorus can increase algal growth. Excess nitrogen from blasting will often be available for algal growth in mine receiving waters, and phosphorus will normally be the nutrient limiting algal growth. Potential phosphorus sources are domestic sewage, fertilizers for reclamation, and leaching of disturbed soil and rock. If phosphorus losses to surface water are expected, their effect on algal growth should be assessed.

(g) Evaluation and Prediction of Impacts

The information assembled in sections (a) to (f) can be used to make a crude evaluation of nitrogen losses from blasting and their probable effect on water quality and algal growth. Predicted nitrogen and phosphorus loadings can be combined with receiving water flows to calculate receiving water concentrations. These concentrations can then be superimposed on the existing water quality and algal situation to predict future water quality and algal growth conditions. These future conditions can then be used to assess the impacts on existing and potential water uses.

5.2 MANAGEMENT OF IMPACTS

5.2.1 INTRODUCTION

There are several ways in which nitrogen losses from explosives use can be managed to minimize the impacts on aquatic resources. The most desirable strategy is to minimize nitrogen losses to water by minimizing contact between explosives and water. Once nitrogen is in water, removing it is difficult, although several techniques can be used to minimize its impact.

5.2.2 MINIMIZING NITROGEN LOSSES

The nitrogen compounds in explosives or produced by detonation are extremely water soluble, and thus contact between explosives, their byproducts, and water should be minimized.

(a) Dewatering Blasting Area

Dewatering of blasting areas can be achieved by methods such as diversions of surface water, pit perimeter wells to draw the pit water table down below the bottom of the blastholes, and/or pumping out each blasthole just before loading with explosives. Dewatering may permit the use of AN/FO, which is cheaper than slurry explosives, thus off-setting the cost of dewatering. Temporarily dewatering blastholes so that slurry can be loaded into dry holes would minimize the relatively large losses that occur when slurry is loaded into holes containing water (see section 3.4.6(c)). Temporary dewatering would also permit the use of AN/FO inside polyethylene hole liners, which is cheaper than slurry, but the effectiveness of this technique in keeping the AN/FO dry (i.e. puncturing of liners in jagged blastholes) has to be considered. The techniques for achieving dry blasting conditions will vary from mine to mine, depending on the costs of dewatering and blasting, and the amount of nitrogen loss that can be tolerated.

(b) Loading to Blasting Time

Minimizing the time that the explosives are exposed to water in the blastholes will minimize nitrogen losses. This is particularly important for AN/FO which has no resistance to water. Slurries are water resistant once the water proofing has set up, but there is some evidence of water attack during prolonged exposure[3]. Reducing the time from the loading to the blasting of explosives would necessitate smaller, more frequent blasts.

(c) Spill Control and Housekeeping

Spill control and good housekeeping are particularly important at explosives blending, handling and storage facilities (e.g. bulk explosives plants) because of the potential for toxic concentrations of nitrate, ammonia and nitrite occurring in water. Spill prevention and collection features should be designed into the facilities, with dry clean-up and recycling of any spills. The yard areas should be paved and curbed so that all yard drainage from the facilities, as well as in-plant effluents, can be collected for appropriate treatment and disposal. (Potential treatment and disposal techniques are discussed in section 5.2.3).

Explosives facilities should be located well away from watercourses to minimize the potential for spills entering water. Explosives facilities are being brought under permit by the Waste Management Branch so that regulation of effluents from these facilities is achieved.

Spills during blasthole loading should be minimized by careful handling practices. Spilled material should be cleaned up and placed in a blasthole, so that it will be detonated instead of remaining in the spoil to be leached out by water.

(d) Diversion of Water Away from Spoil

Spoil can contain substantial amounts of residual nitrogen from blasting that can be leached out by water (see section 3.5.5). Minimizing the water available for leaching by diverting water away from spoil piles will reduce the nitrogen leaching rate. This will reduce nitrogen loadings and concentrations in the receiving waters by spreading the leaching over a longer time period. Diversion of water also reduces the quantity of leachate, thus rendering it more amenable to treatment and disposal as outlined in section 5.2.3. Stability and sediment control considerations also require that water be diverted away from spoil piles, unless the piles are designed to allow water to flow beneath them.

5.2.3 MANAGING NITROGEN IN WATER

Once nitrogen from explosives has entered water, removing it is difficult, but several techniques can be used to reduce its impact.

(a) Recycling

Recycling is probably the most common technique used at mines in British Columbia to manage nitrogen in water. Nitrogen-rich drainage from pits, spoil piles and bulk explosives plants is discharged to tailing ponds that are normally substantially water-tight, and then recycled for process make-up water. Fording Coal Ltd. has used its tailing ponds to recycle pit water and explosives plant effluent. Having a water-tight tailings pond at a mine is a valuable asset in the management of nitrogen-rich water.

(b) Storage

Storage or retention of nitrogen-rich drainage in pits, settling ponds or in the groundwater system can be a useful technique in managing nitrogen. Dissolving explosives in water results in roughly equal concentrations of nitrate and ammonia because explosives nitrogen is mainly present as ammonium nitrate. Under aerobic conditions, ammonia, which is highly toxic to aquatic life, is oxidized to nitrite (also highly toxic to aquatic life) and then to nitrate, which is relatively non-toxic. This process is called nitrification, and its rate is temperature dependent. The rate is relatively rapid at summer temperatures (e.g. a few hours to a few weeks), but approaches zero as 0°C is reached.

Aerobic storage is thus useful in reducing the toxicity of explosives-contaminated water. It can also be used to store nitrogen-rich water during low flows for subsequent discharge during high flows when dilution is available to reduce concentrations to acceptable levels. Similarly, in the more arid parts of the province, nitrogen-rich water could be stored during the winter for use in spray irrigation or spray evaporation during the summer.

(c) Land Application

Land application includes infiltration and irrigation, and is preferable to discharge to surface water for several reasons. Land disposal can allow several processes to occur that can lessen the impact of nitrogen on water. Infiltration of nitrogen-rich water to groundwater provides some dilution, and tends to attenuate or smooth out peaks in nitrogen concentration. Under aerobic conditions, nitrification will occur, oxidizing more toxic ammonia and nitrite to less toxic nitrate. Under anaerobic conditions, denitrification can occur, releasing nitrogen gas to the atmosphere, and reducing the nitrogen content of the water. A soluble organic carbon energy source is necessary for denitrification to occur. Ammonium will be removed by adsorption on the cation-exchange complex of the soil.

Irrigation will result in the uptake and storage of some nitrogen by plants. Maximum plant uptake is about 100 to 700 kg N ha^{-1} y, depending on the crop, and the crop must be removed to achieve permanent N removal (see section 2.5.3(e)). In addition, the climate, soils and topography of the area must be suitable for the application of the quantity of water necessary to achieve the desired N application.

(d) Treatment Methods

The treatment processes available to remove nitrogen from water were reviewed in section 2.5. These include biological nitrification (NH_4^+, NH_3, NO_2^- removal), biological denitrification (NO_3^- removal), breakpoint chlorination (NH_4^+, NH_3 removal), ammonia stripping (NH_4^+, NH_3 removal), ion exchange (NH_4^+, NH_3, NO_3^- removal), and land disposal (NH_4^+, NH_3, NO_2^-, NO_3^- removal). With the exception of land disposal, which was discussed above, these treatment methods are complex and costly, and have not been applied to mining effluents. It is expected that these methods would not be used unless all other nitrogen management options were exhausted.

(e) Phosphorus Control

Phosphorus control is an important consideration in the managing of nitrogen, because excess nitrogen for algal growth will often be present in mine receiving waters, and phosphorus will usually be the nutrient limiting algal growth. Consequently, efforts should be made to minimize phosphorus discharge to surface water. Domestic sewage will usually be the only significant source of phosphorus, and it can often be prevented from reaching surface water by land disposal or recycling via a tailings pond. Fertilizer application during reclamation is a potential phosphorus source, and care should be taken to minimize losses to surface water.

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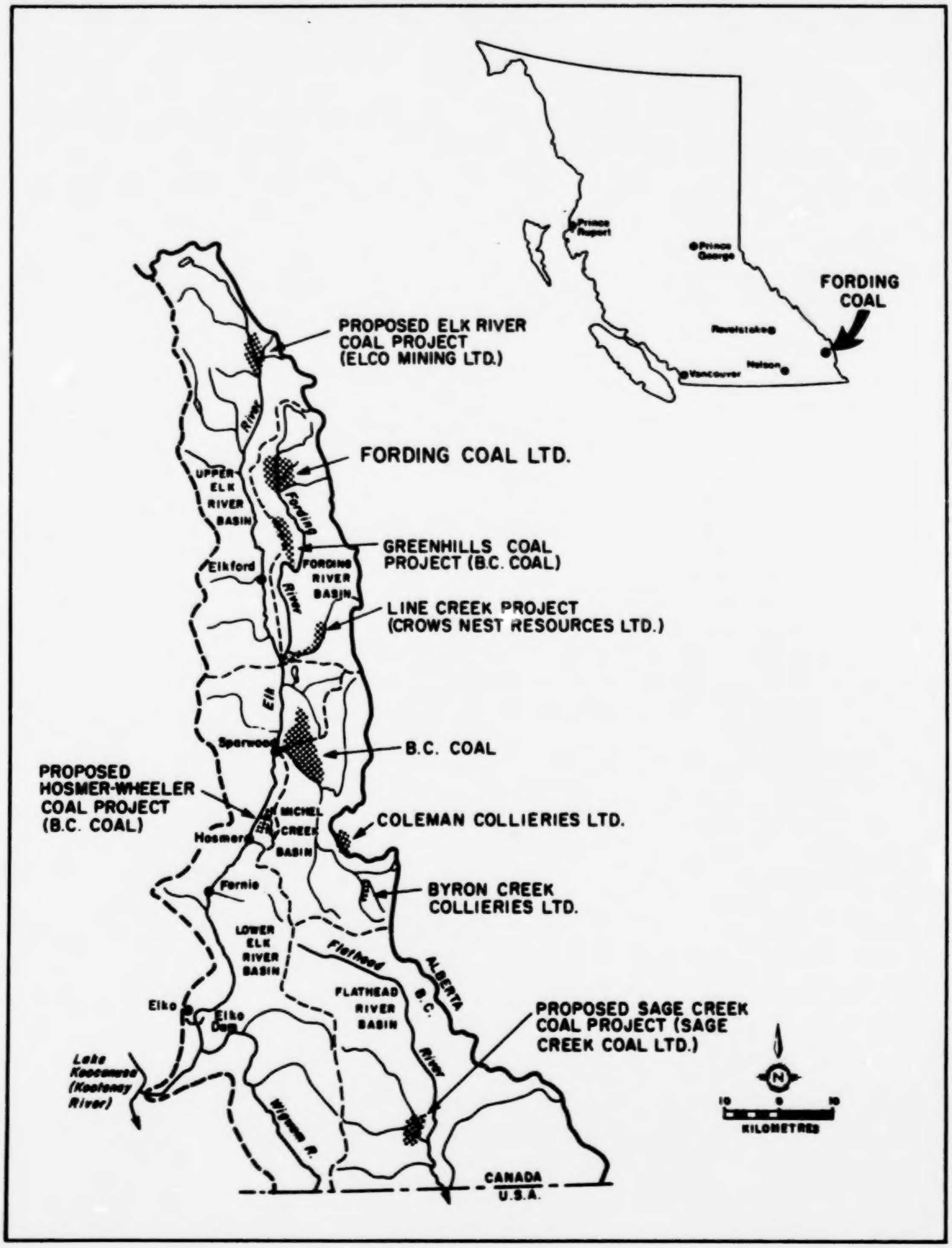

Figure 1 Location of Study Area

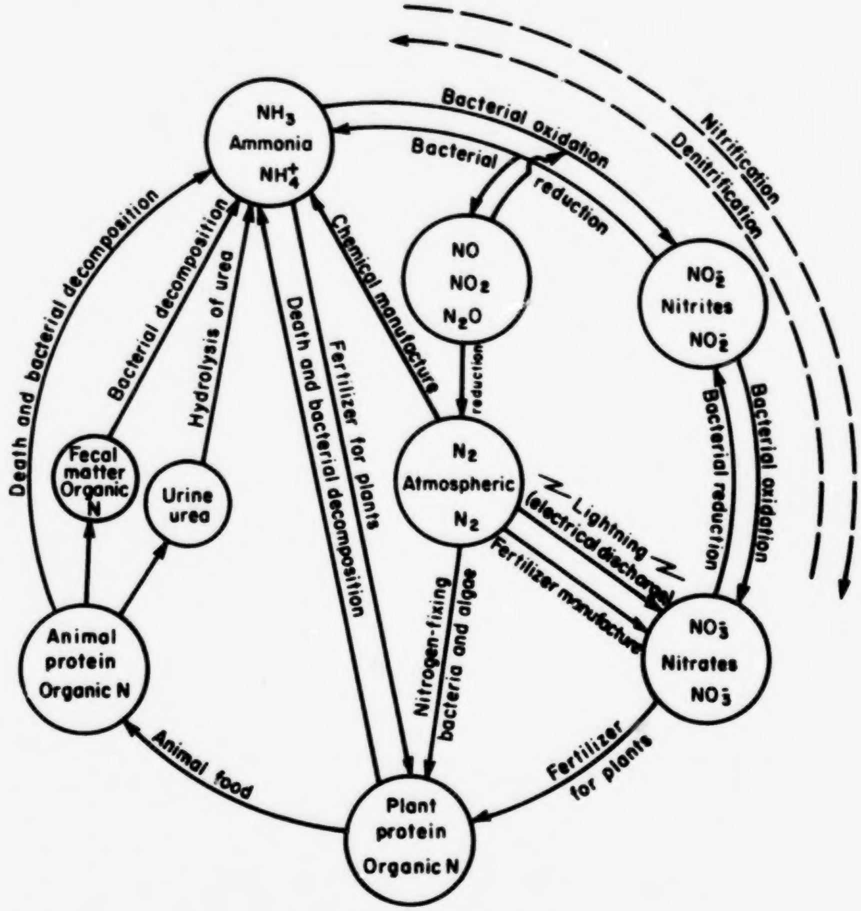

Figure 2 The Nitrogen Cycle*

*Adapted from Sawyer and McCarty, 1967.

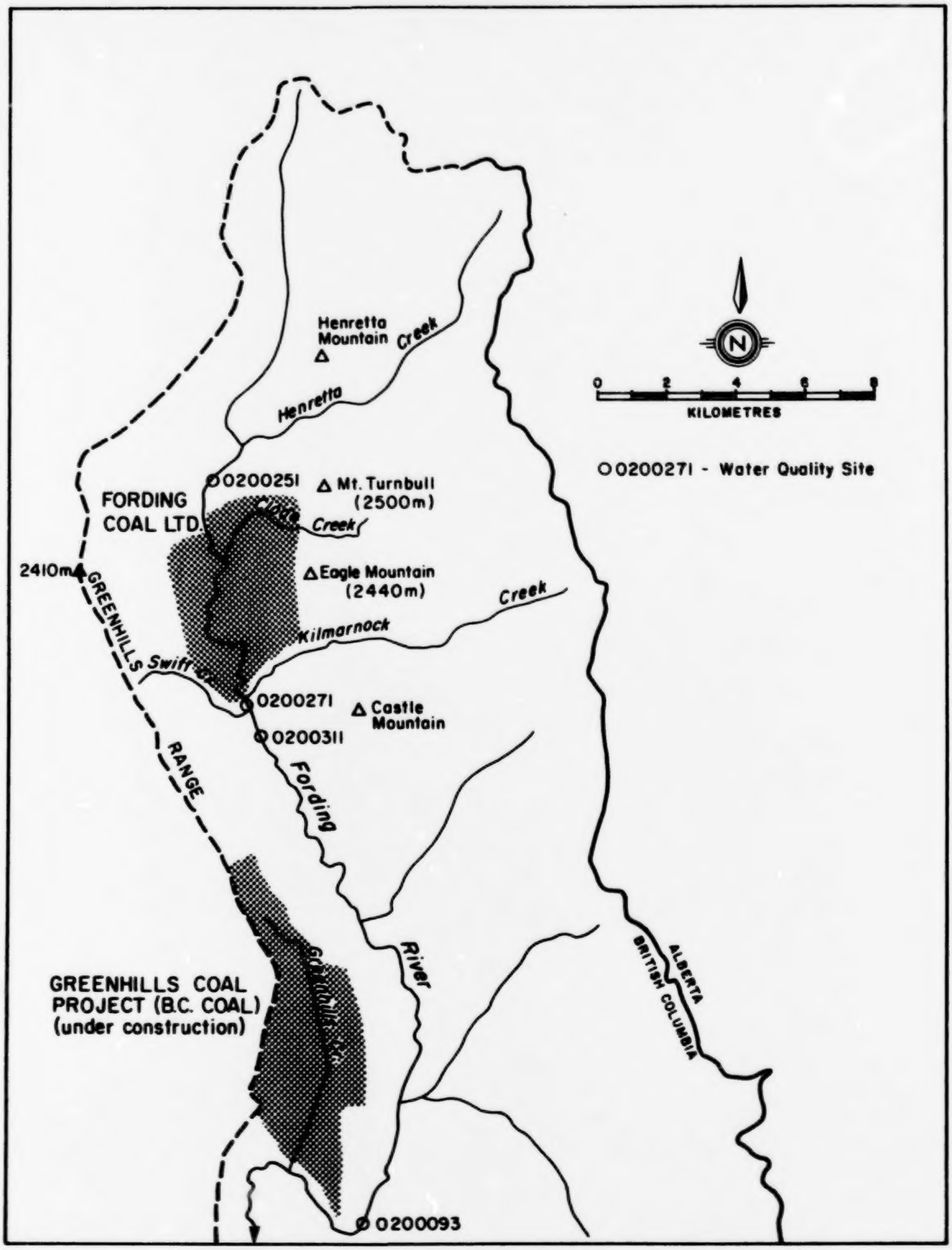

Figure 3 The Fording River Basin

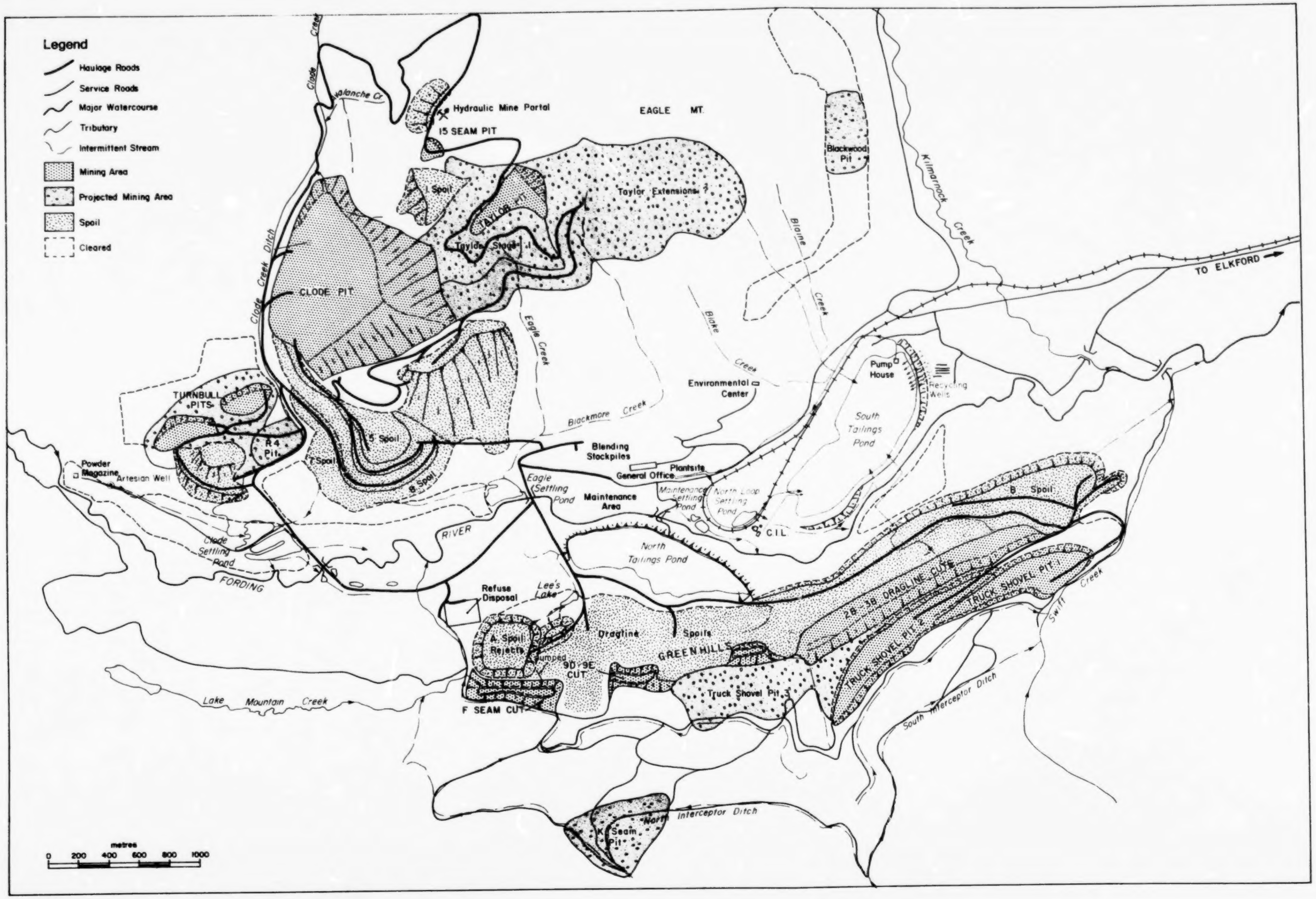

Figure 4 Fording Coal Limited Mine

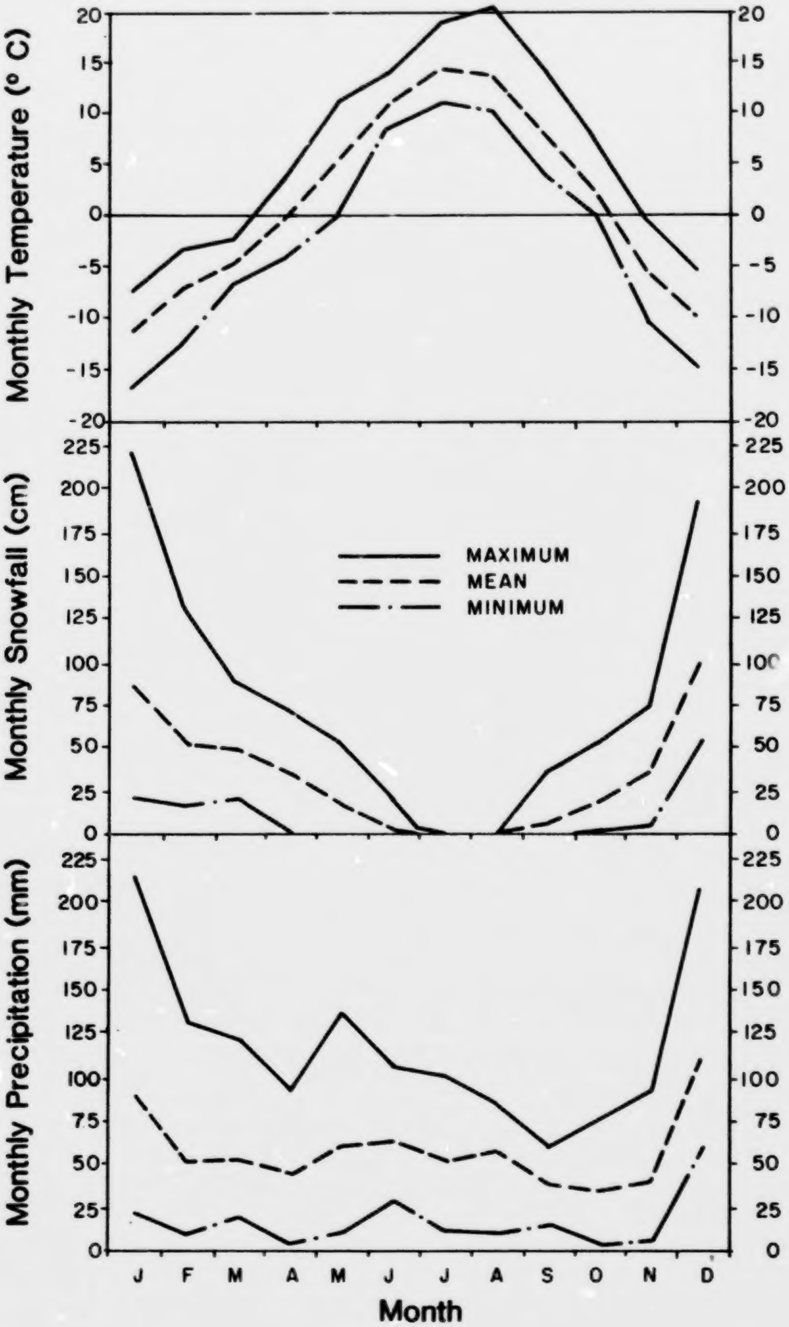

Figure 5 Monthly Total Precipitation, Snowfall and Temperature at Fording Coal Limited, 1970-79. (Fording River Cominco Station, 50°11', 114°52', 1658-1702 masl)

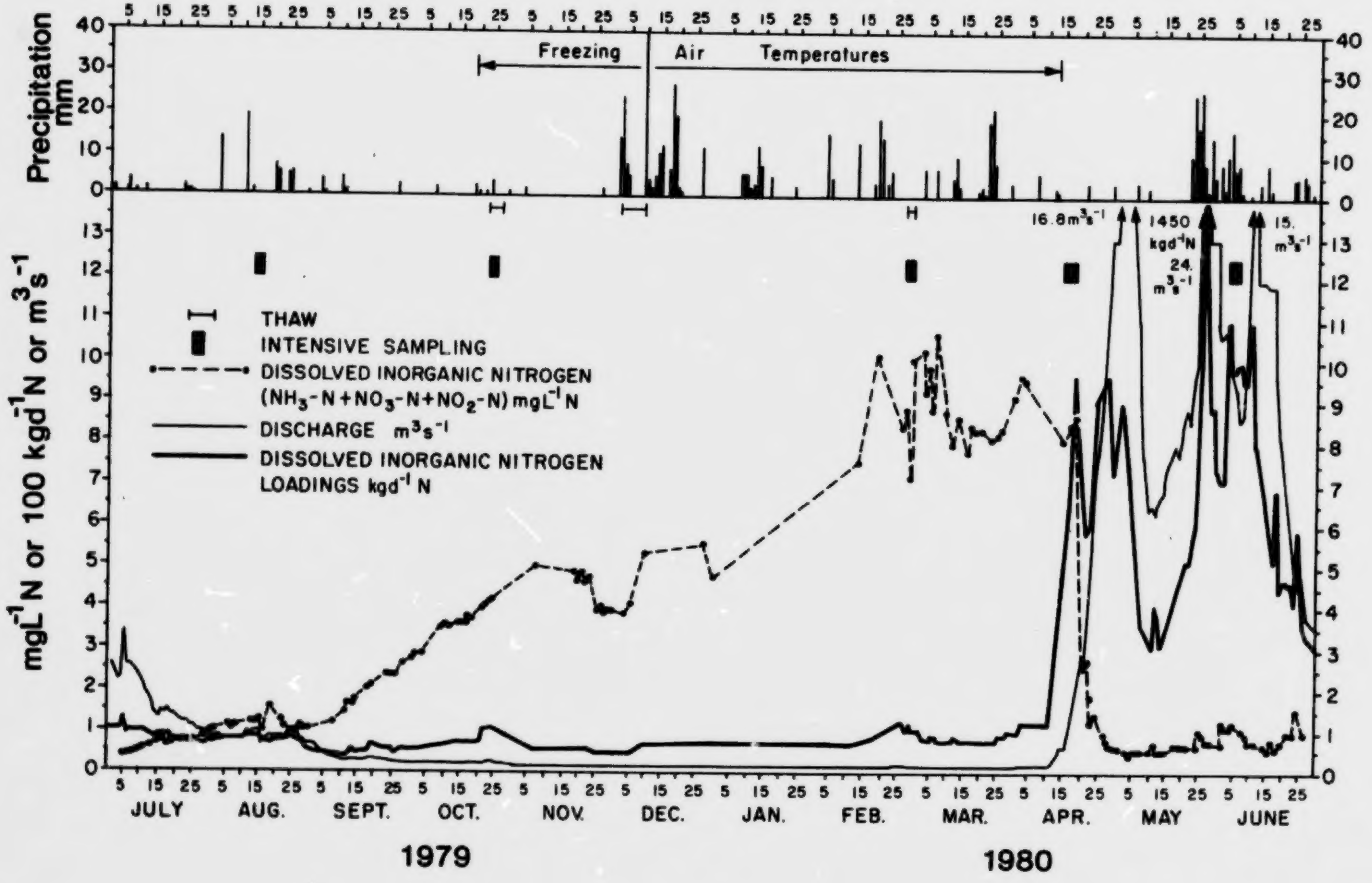

Figure 6 Fording River Downstream Fording Coal Limited, Discharge, Nitrogen Concentrations and Loadings, July 1979 - June 1980.

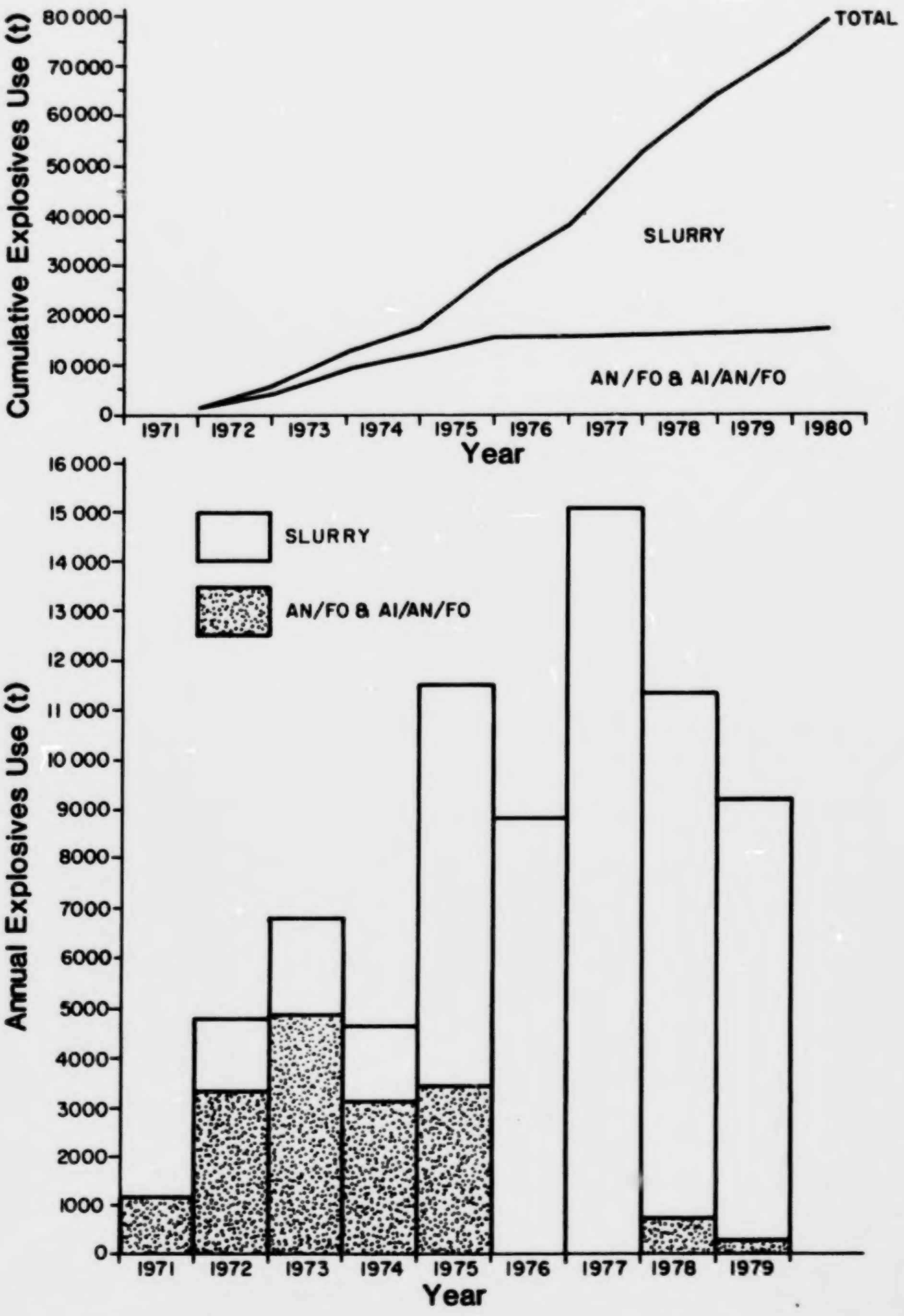

Figure 7 Explosives Use at Fording Coal Limited, 1971-80.

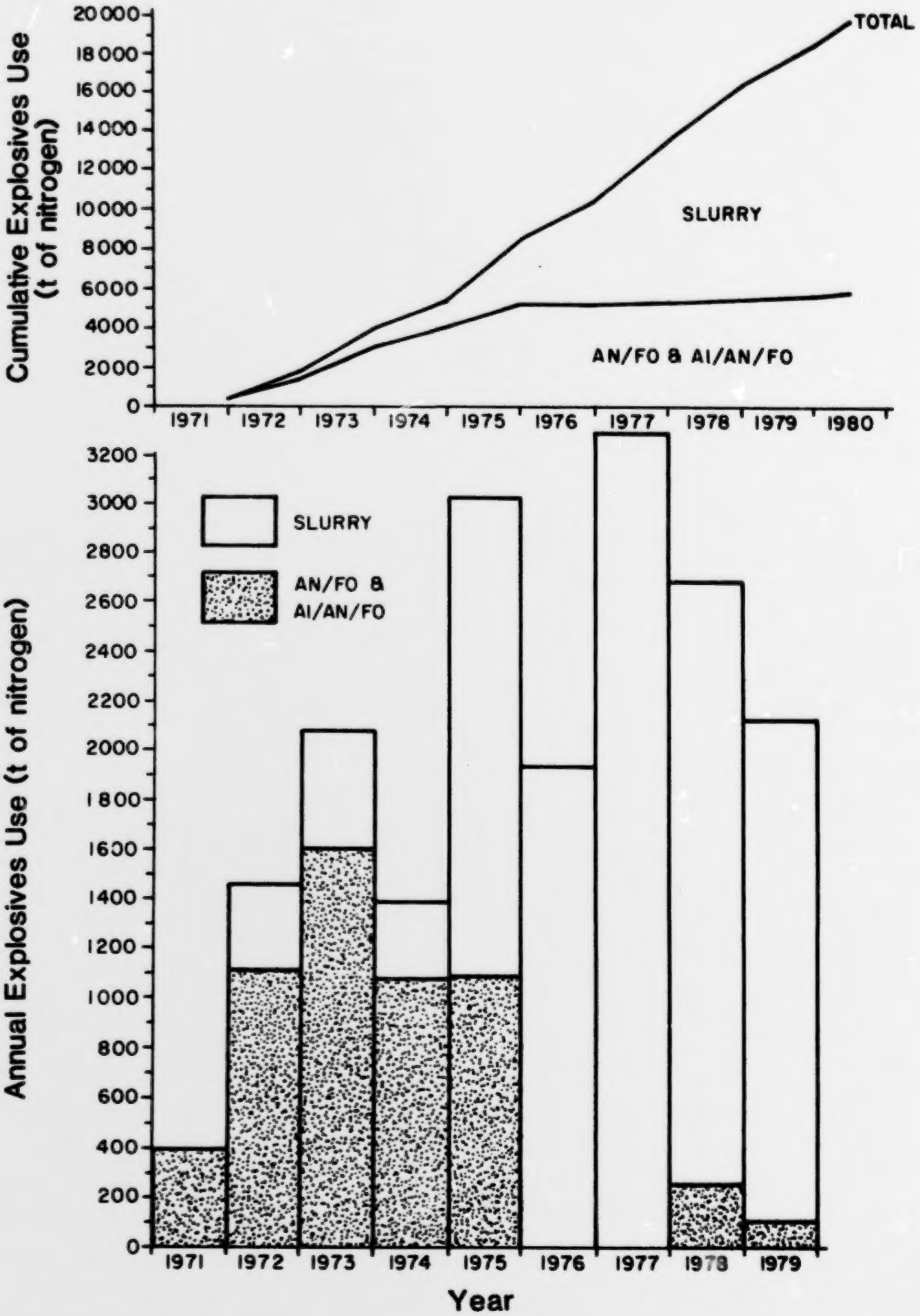

Figure 8 Explosives Use (Tonnes of Nitrogen) at Fording Coal Limited, 1971-80.

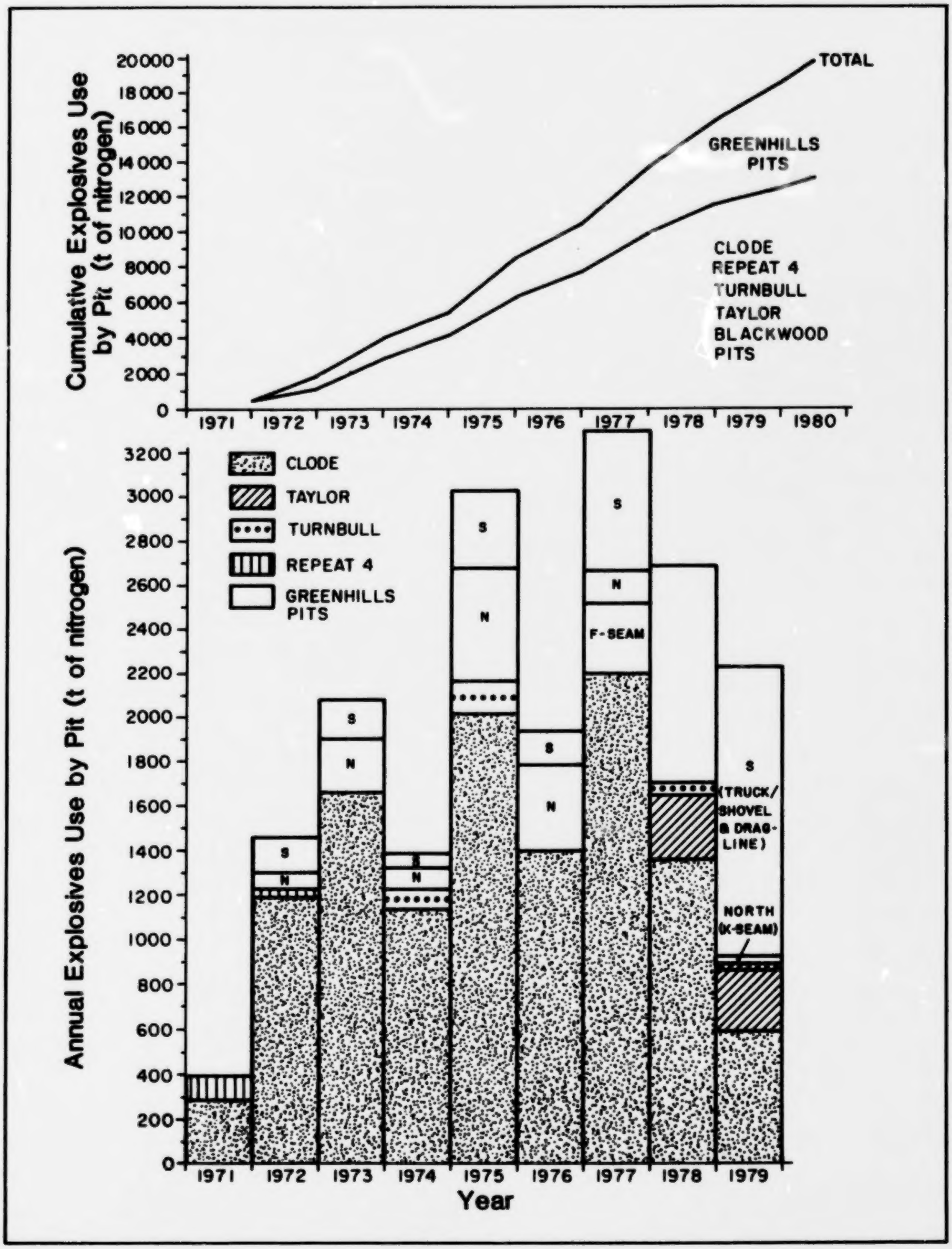

Figure 9 Explosives Use (Tonnes of Nitrogen) by Pit at Fording Coal Limited, 1971-80.

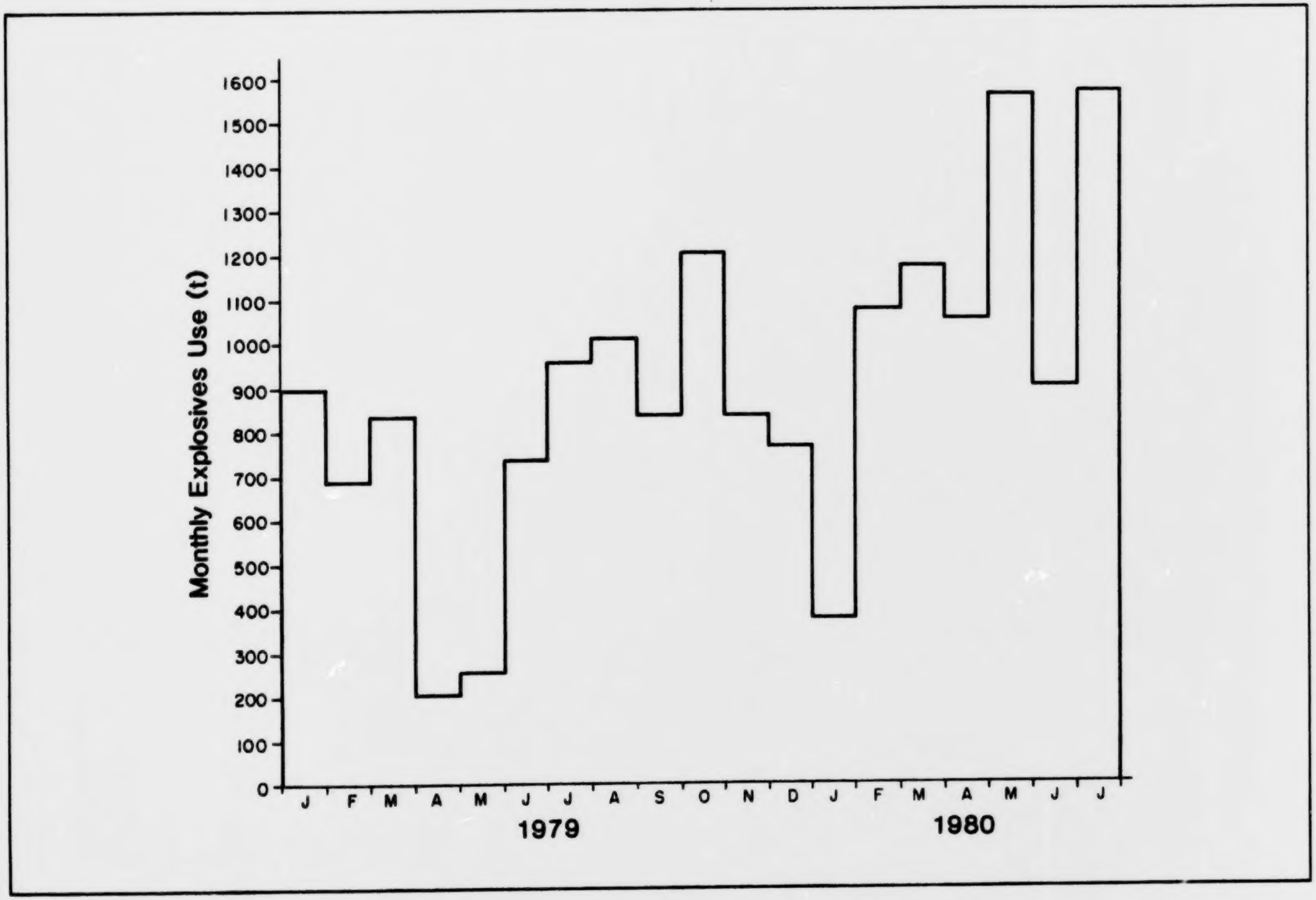

Figure 10 Monthly Explosives Use at Fording Coal Limited, January 1979 to July 1980.

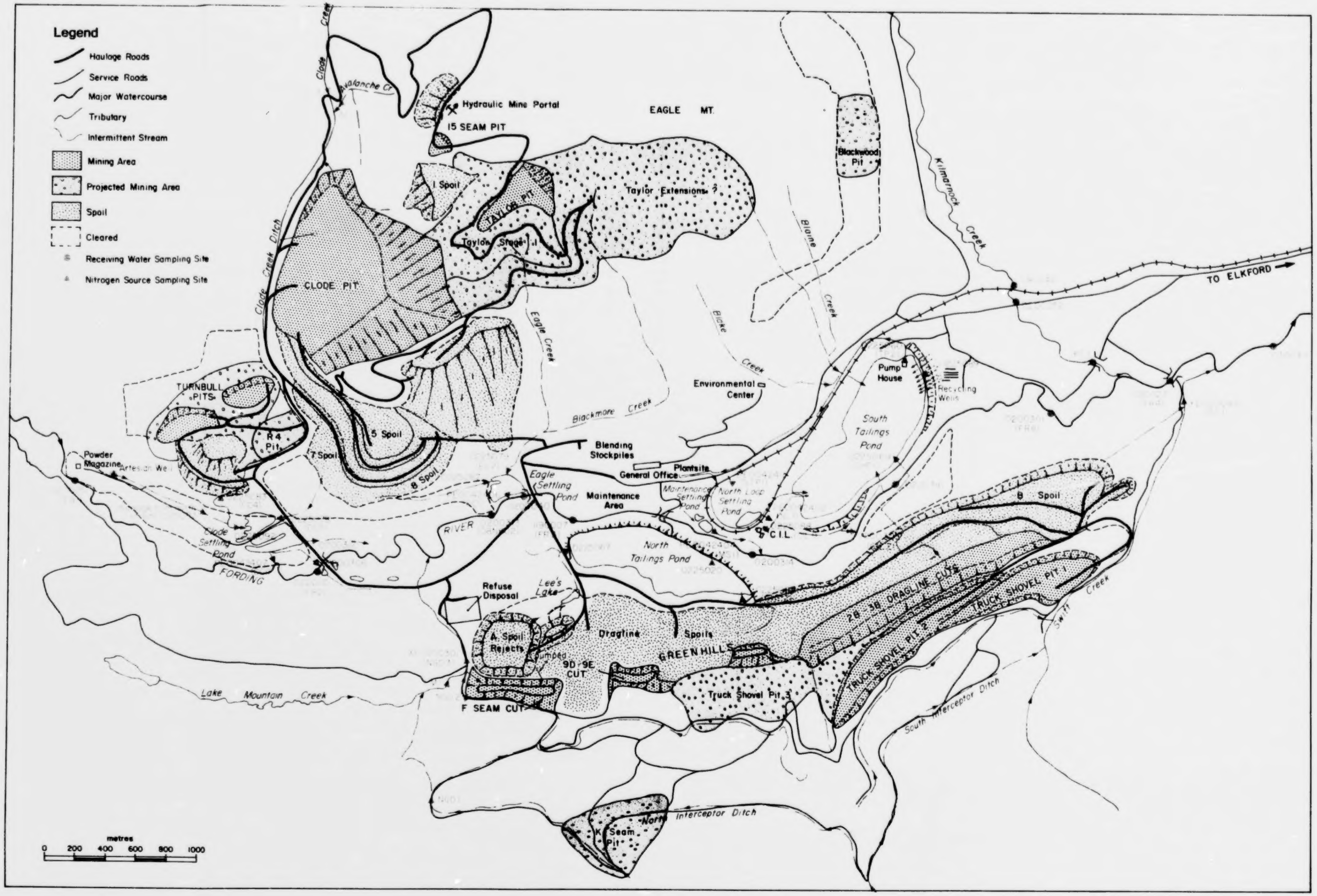

Figure 11 Sampling sites at Fording Coal Limited

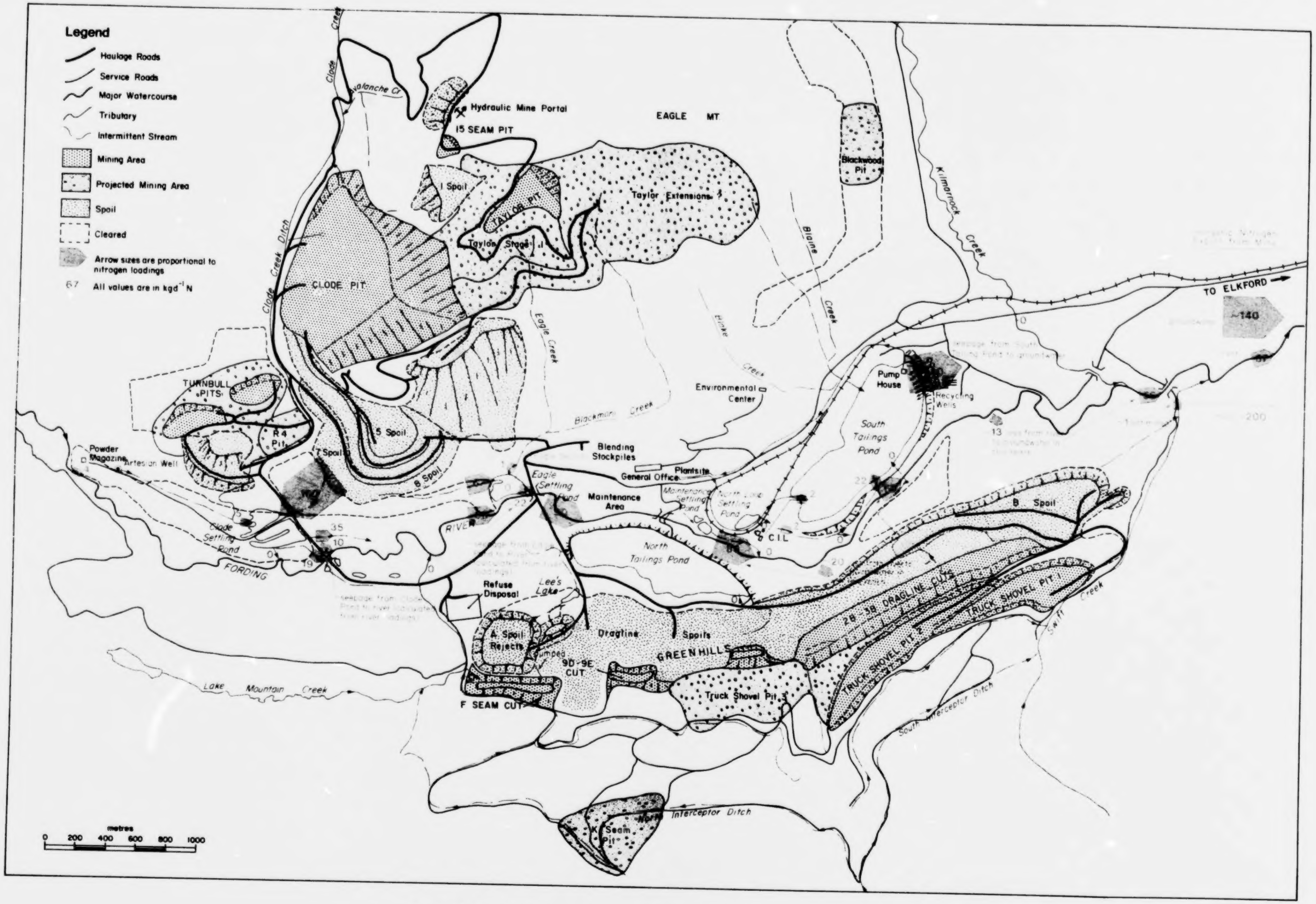

Figure 12 Inorganic nitrogen[1] balance at Fording Coal Ltd., August 14–16, 1979
[1](inorganic nitrogen = NO_3-N+NO_2-N+NH_3-N)

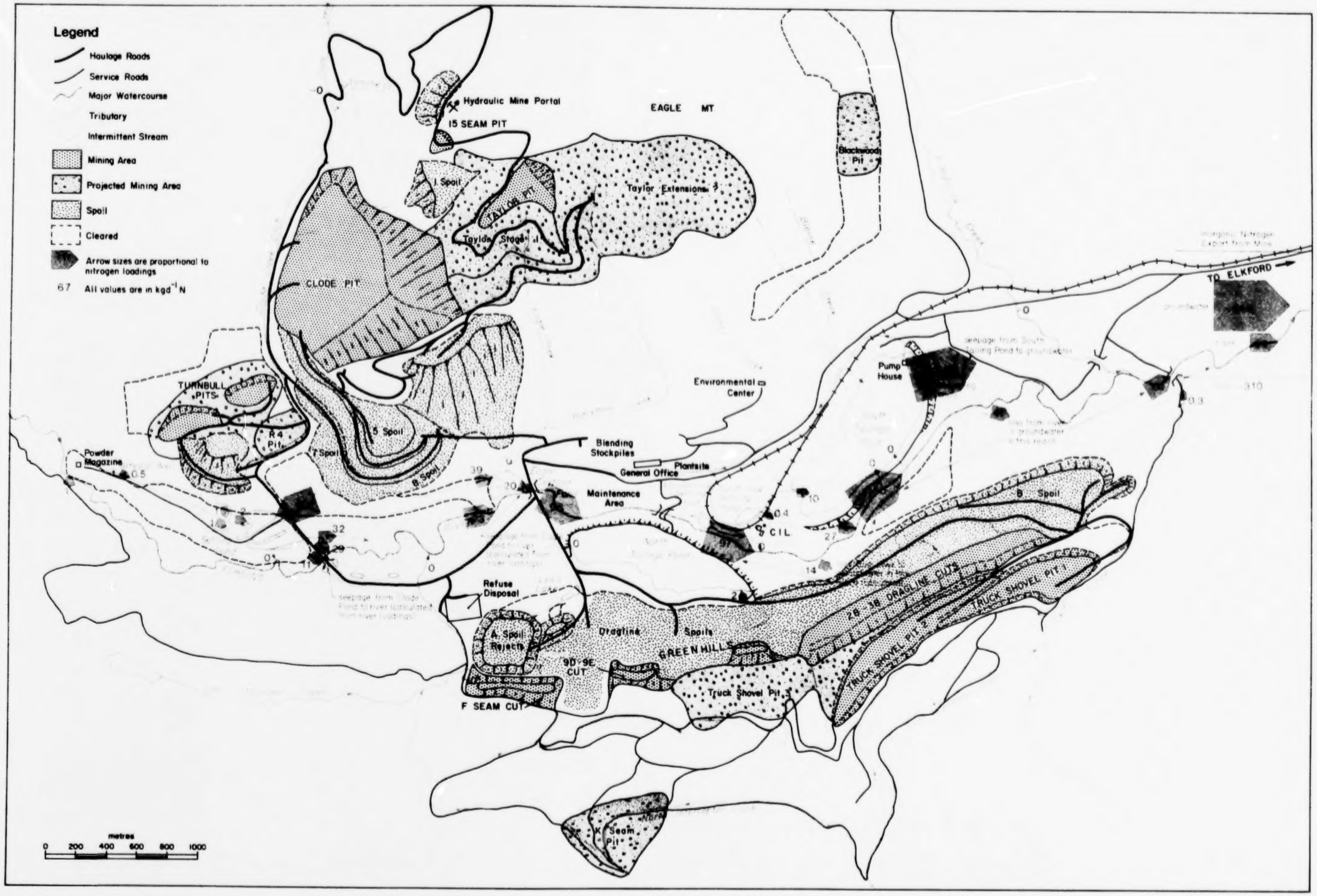

Figure 13 Inorganic nitrogen balance at Fording Coal Ltd., October 23–25, 1979
(inorganic nitrogen = NO_3–N + NO_2–N + NH_3–N)

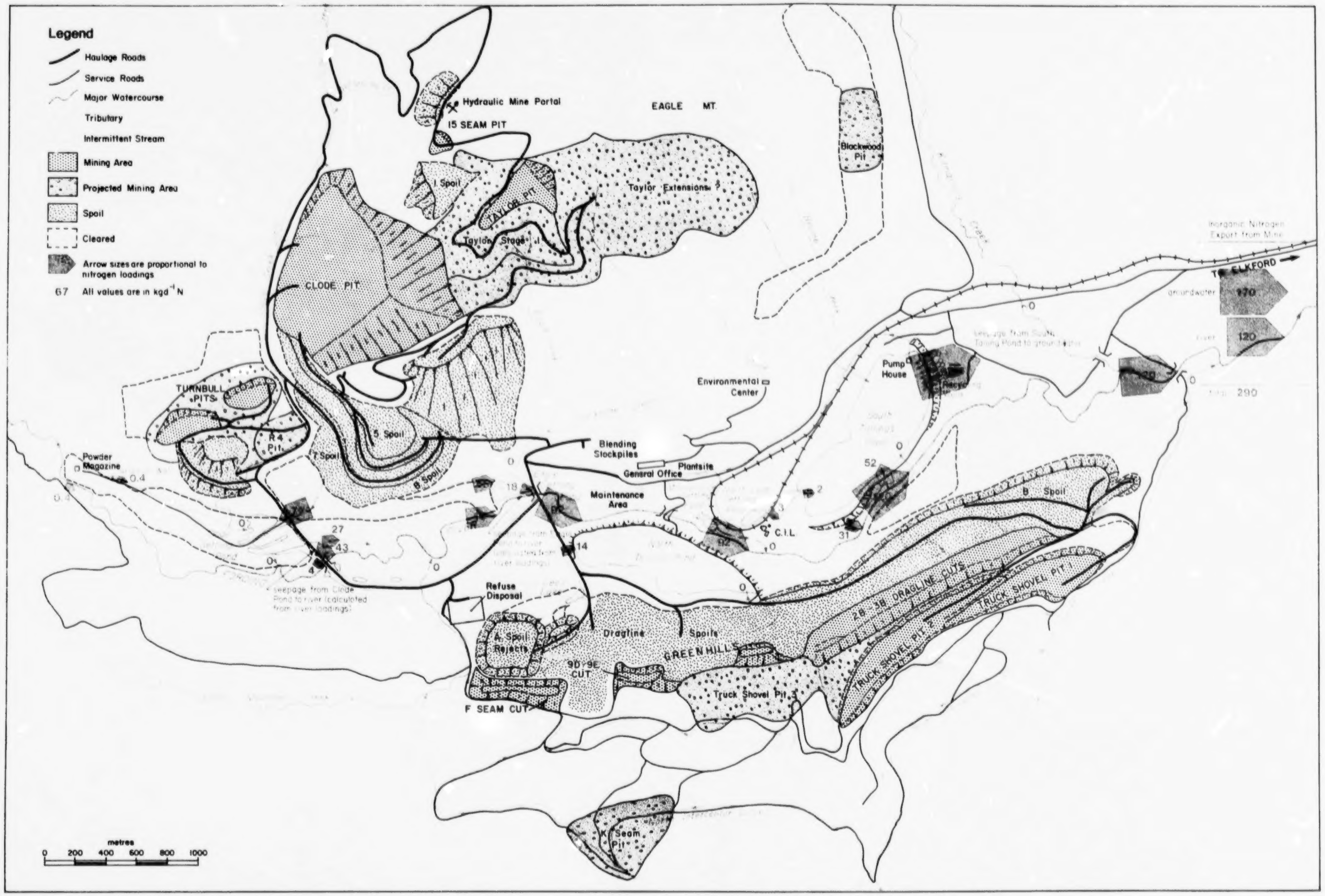

Figure 14 Inorganic nitrogen[1] balance at Fording Coal Ltd., February 26-28, 1980

[1](inorganic nitrogen = NO_3-N+NO_2-N+NH_3-N)

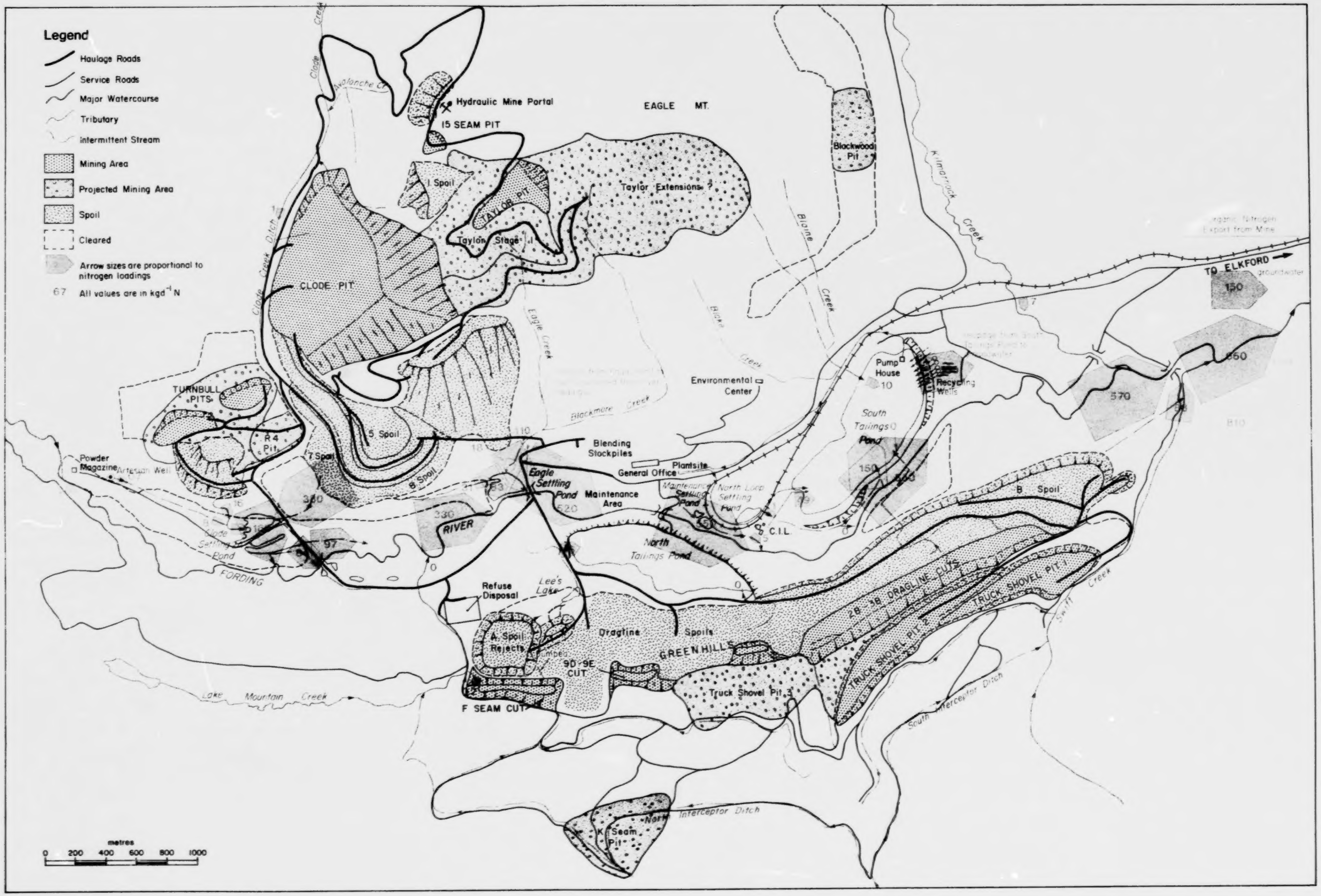

Figure 15 Inorganic nitrogen[1] balance at Fording Coal Ltd., April 14-17, 1980

[1](inorganic nitrogen = NO_3-N + NO_2-N + NH_3-N)

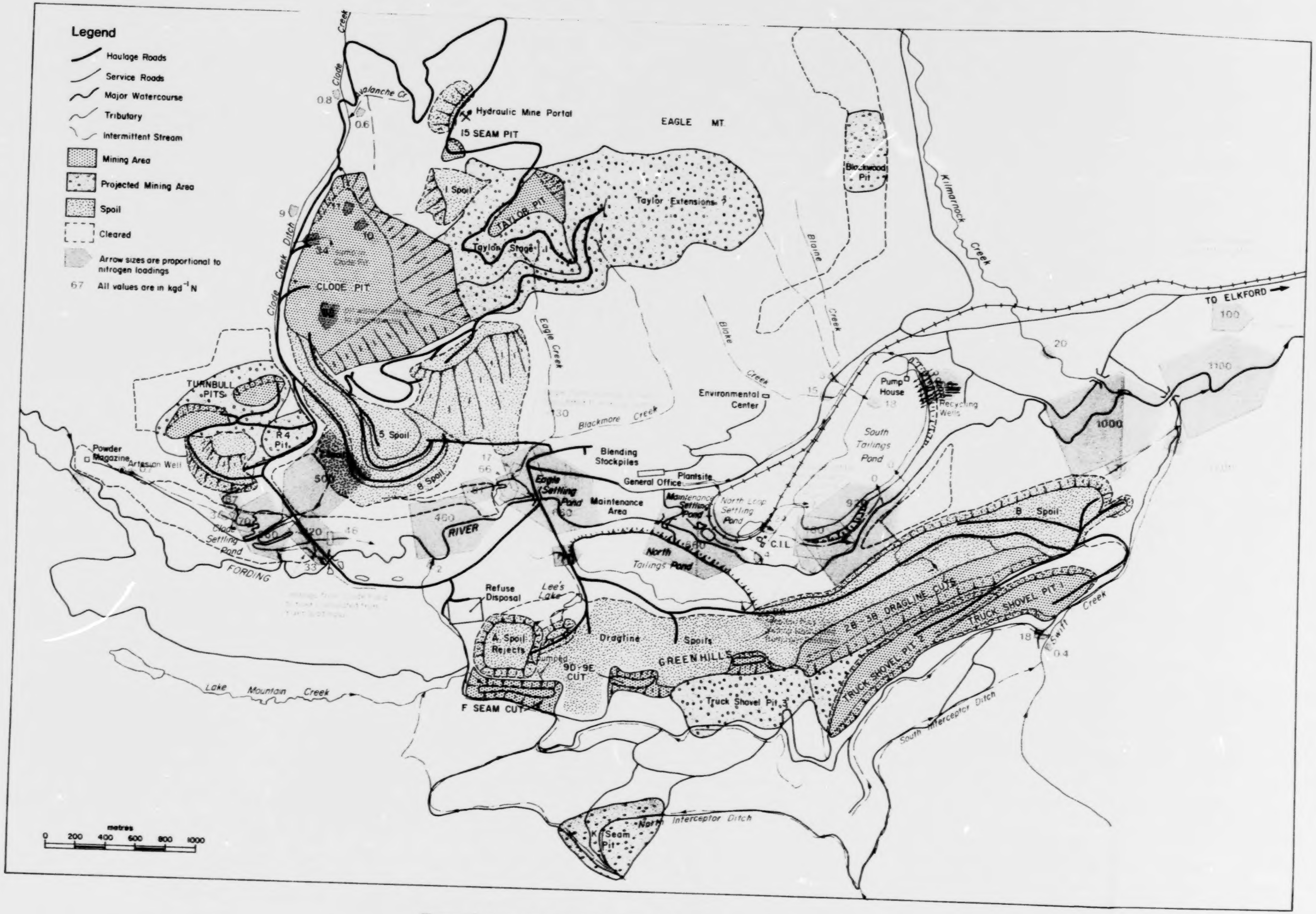

Figure 16 Inorganic nitrogen[1] balance at Fording Coal Ltd. June 3-5, 1980

[1](inorganic nitrogen = NO_3-N+NO_2-N+NH_3-N)

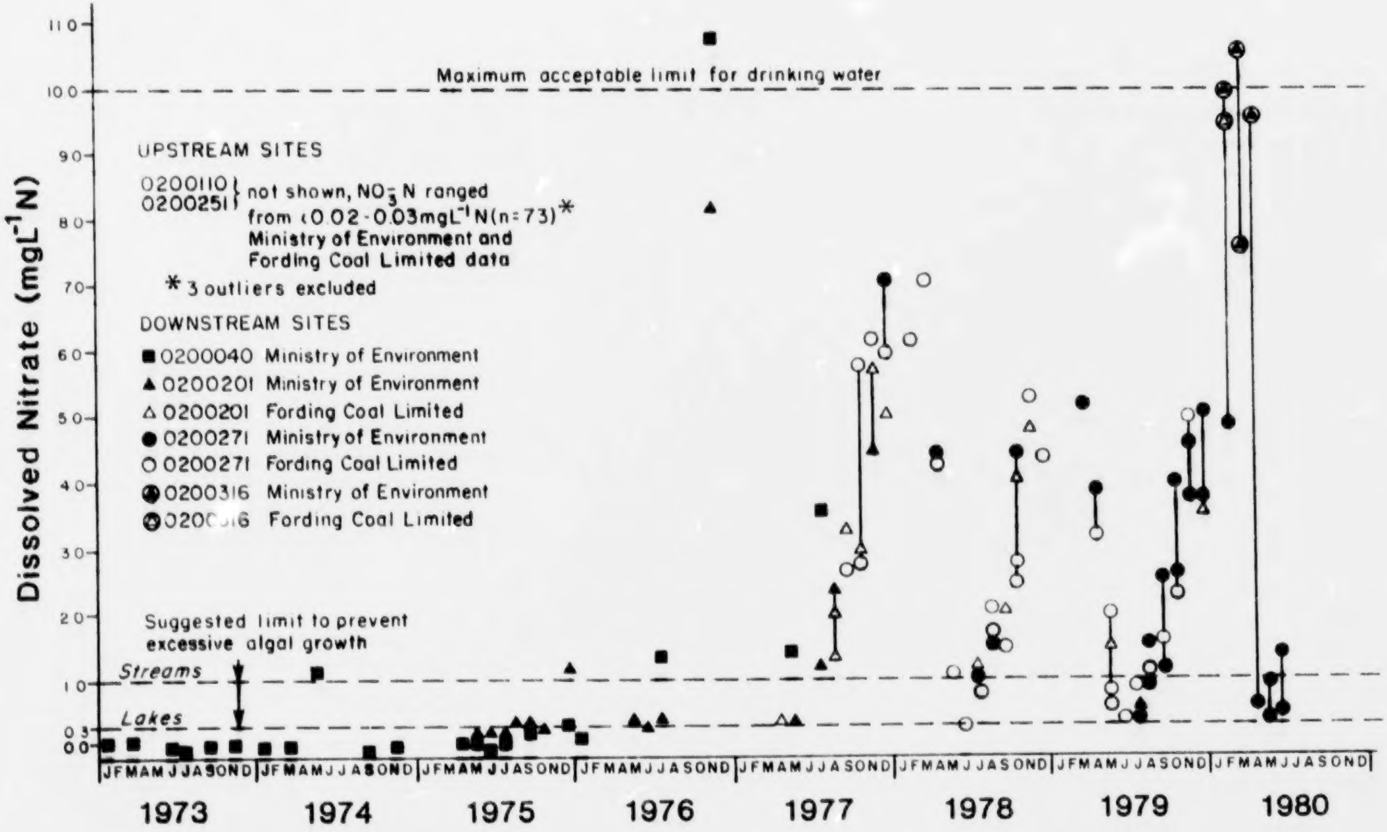

Figure 17 Dissolved Nitrate Nitrogen in the Fording River at Fording Coal Limited, 1973-1980.

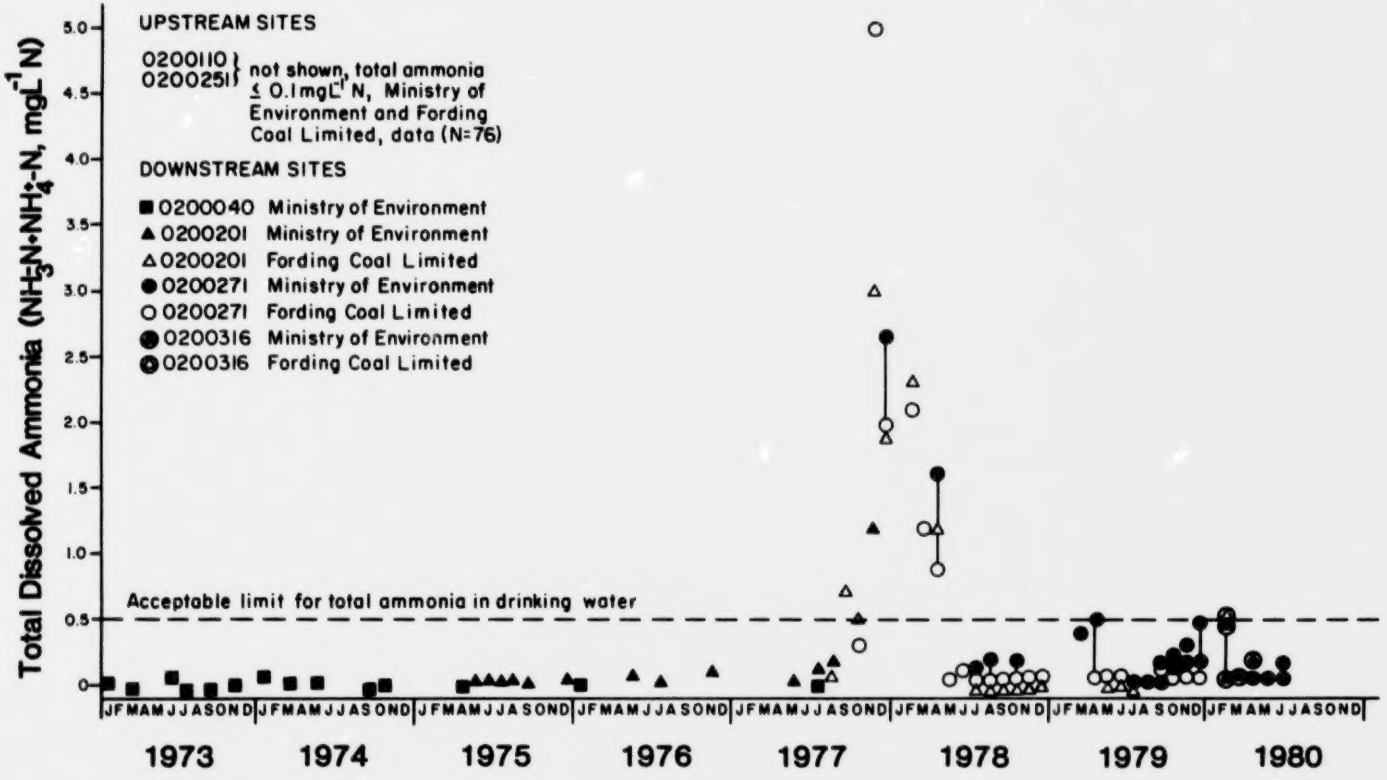

Figure 18 Total Ammonia Nitrogen in the Fording River at Fording Coal Limited, 1973-1980.

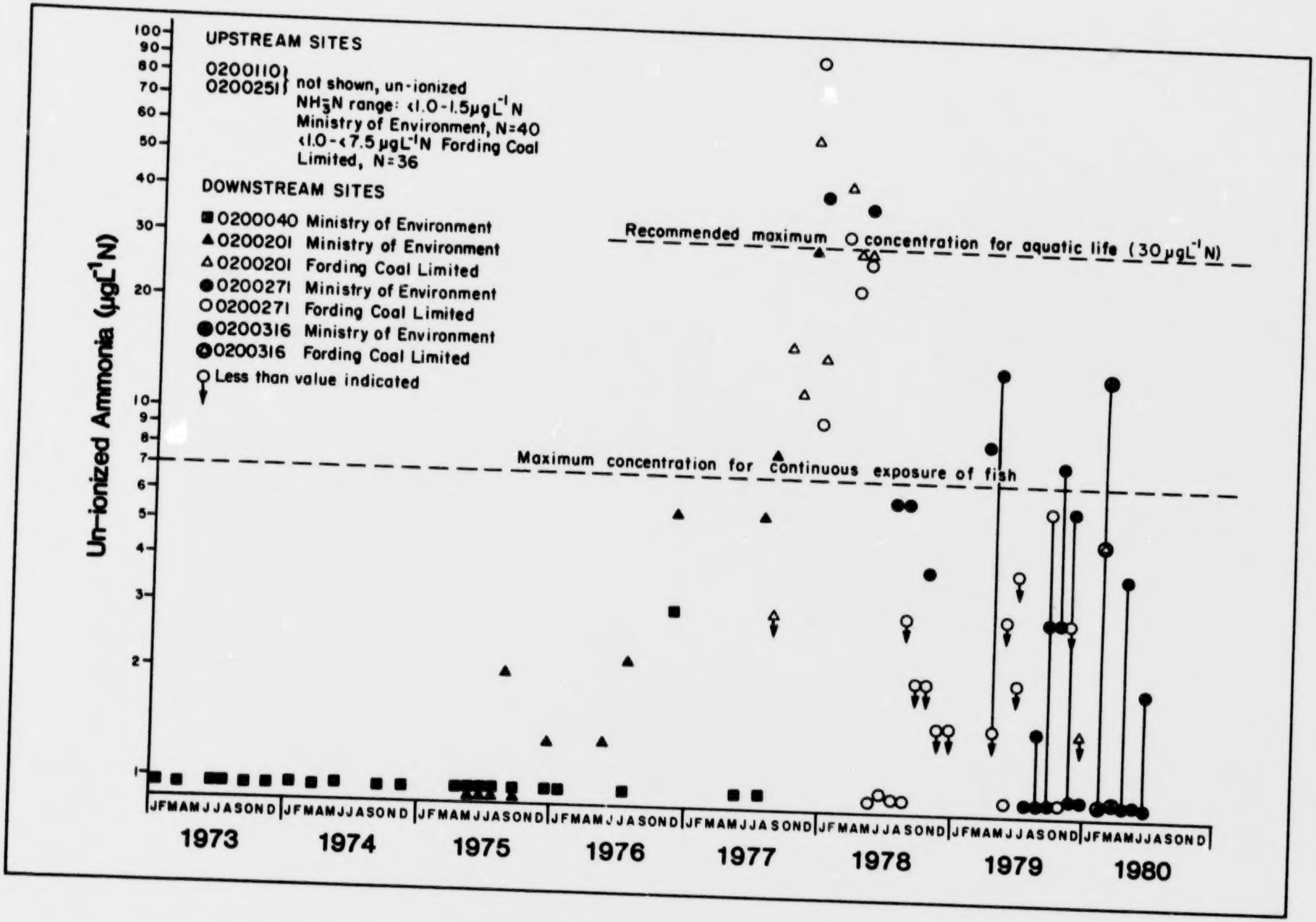

Figure 19 Un-ionized Ammonia Nitrogen in the Fording River at Fording Coal Limited, 1973-1980.

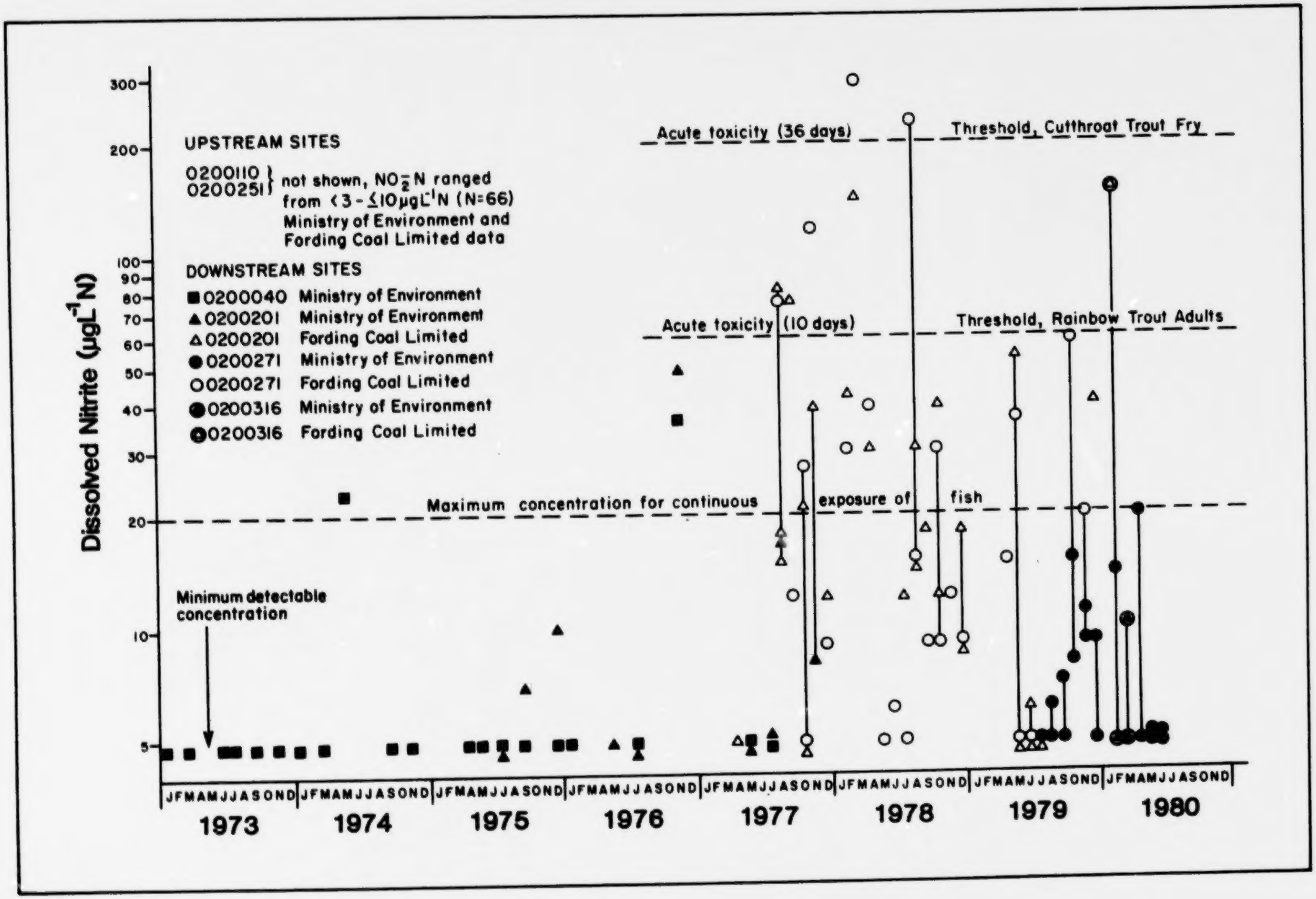

Figure 20 Nitrite Nitrogen in the Fording River at Fording Coal Limited, 1973-1980.

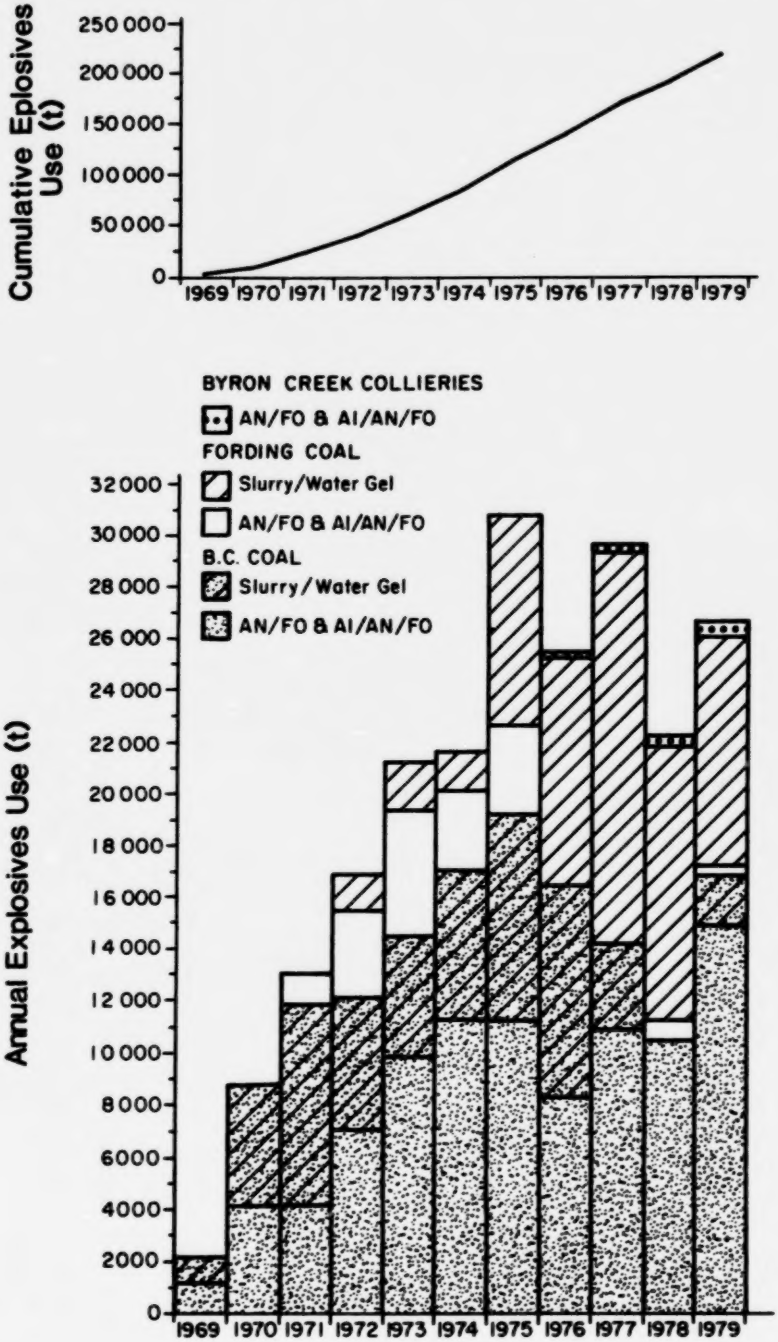

Figure 21 Explosives Use at Surface Coal Mines in the Elk River Basin, 1969-1979.

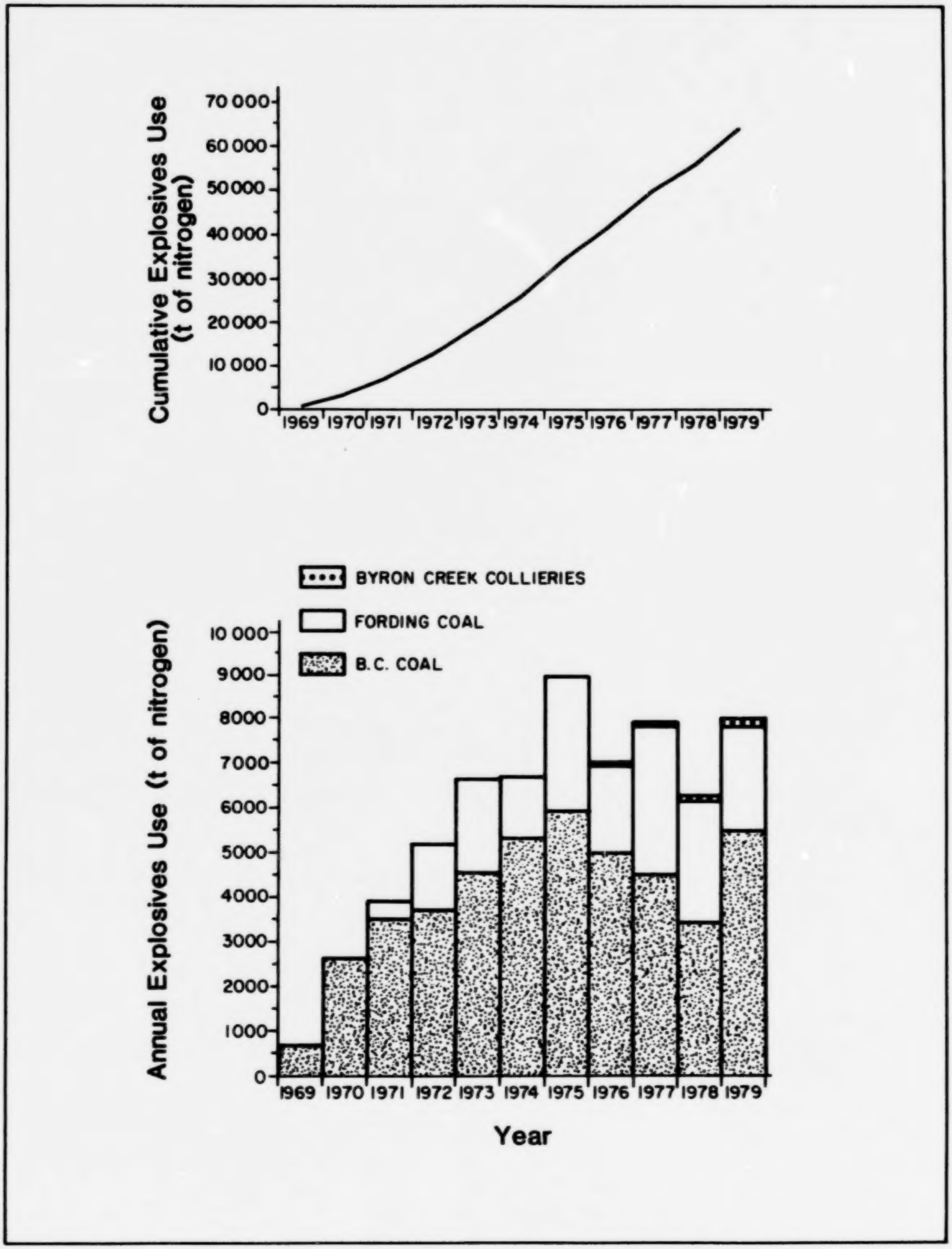

Figure 22 Explosives Use (Tonnes of Nitrogen) at Surface Coal Mines in the Elk River Basin, 1969-1979.

TABLE 1: EFFECT OF VARIOUS TREATMENT PROCESSES ON NITROGEN COMPOUNDS*

TREATMENT PROCESS	EFFECT ON CONSTITUENT			REMOVAL OF TOTAL NITROGEN ENTERING PROCESS, PERCENT[a]	COMMENTS
	ORGANIC N	NH_3/NH_4^+	NO_3^-		
Conventional treatment processes					
Primary	10-20% removed	no effect	no effect	5-10	Not applicable to explosives wastewater
Secondary	15-25% removed[b] urea → NH_3/NH_4^+	<10% removed	nil	10-20	
Advanced wastewater treatment processes					
Filtration[c]	30-95% removed	nil	nil	20-40	Not applicable to explosives wastewater
Carbon sorption	30-50% removed	nil	nil	10-20	
Electrodialysis	100% of suspended organic N removed	40% removed	40% removed	35-45	Not in full scale use (1978)[60]
Reverse osmosis	100% of suspended organic N removed	85% removed	85% removed	80-90	
Chemical coagulation[c]	50-70% removed	nil	nil	20-30	Not applicable to explosives wastewater
Land application					
Irrigation	→ NH_3/NH_4^+	→ NO_3^- → plant N	→ plant N	40-90	Limited by plant uptake and irrigable land requirements
Infiltration/percolation	→ NH_3/NH_4^+	→ NO_3^-	→ N_2	0-50	90+% if C source added, low efficiency at low temperatures
Major nitrogen removal processes					
Nitrification	limited effect	→ NO_3^-	no effect	5-10	Temperature dependent
Denitrification	no effect	no effect	80-98% removed	70-95	C source required, low efficiency at low temperatures
Breakpoint chlorination	uncertain	90-100% removed	no effect	80-95	
Selective ion exchange for ammonium	some removal, uncertain	90-97% removed	no effect	80-95	Not in full scale use (July 1976)[60] Pretreatment and regenerant disposal required
Ammonia stripping (air or steam)	no effect	60-95% removed	no effect	50-90	Not operable below 0°C
Other nitrogen removal processes					
Selective ion exchange for nitrate	nil	nil	75-90% removed	70-90	Pretreatment and regenerant disposal required
Oxidation ponds	partial transformation to NH_3/NH_4^+	partial removal by stripping	partial removal by nitrification-dentrification	20-90	
Algae stripping (harvesting)	partial transformation to NH_3/NH_4^+	→ cells	→ cells	50-80	
Bacterial assimilation	no effect	40-70% removed	limited effect	30-70	

[a] Will depend on the fraction of influent nitrogen for which the process is effective, which may depend on other processes in the treatment plant.
[b] Soluble organic nitrogen, in the form of urea and amino acids, is substantially reduced by secondary treatment.
[c] May be used to remove particulate organic carbon in plants where ammonia or nitrate are removed by other processes.

* Adapted from: U.S. Environmental Protection Agency, Process Design Manual For Nitrogen Control, Office of Technology Transfer, Washington, D.C., 1975.

TABLE 2: HISTORICAL STREAMFLOW SUMMARY, FORDING RIVER BELOW CLODE CREEK*

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	MEAN	MAXIMUM DAILY	MINIMUM DAILY	YEAR
1971	-	-	-	-	9.54	11.04	3.48	1.57	0.86	0.80	0.54	0.33	-	22.2 (May 28)	-	1971
1972	0.35	0.40	0.39	0.54	8.10	13.73	4.36	2.77	1.22	0.92	0.60	0.51	2.83	25.5 (May 31)	0.31 (Jan. 1)	1972
1973	0.39	0.31	0.26	0.51	4.84	7.53	2.59	0.95	0.96	0.54	0.41	0.31	1.63	24.7 (Jun. 8)	0.19 (Mar. 20)	1973
1974	0.29	0.23	0.24	1.24	4.67	15.80	4.62	1.63	0.94	0.62	0.45	0.41	2.59	33.1 (Jun. 14)	0.22 (Feb. 24)	1974
**1975	0.35	0.29	0.29	0.56	3.94	10.73	5.38	1.77	1.26	0.89	0.66	0.50	2.22	17.3 (Jun. 20)	0.27 (Feb. 9)	1975**
1976	0.41	0.31	0.28	1.94	7.31	4.64	3.28	3.26	1.52	0.83	0.48	0.35	2.06	12.5 (May 11)	0.25 (Mar. 6)	1976
1977	0.29	0.27	0.35	1.49	3.37	3.94	1.21	1.38	1.24	0.77	0.40	0.27	1.25	8.0 (Jun. 7)	0.19 (Nov. 23)	1977
1978	0.23	0.23	0.35	0.78	4.59	7.31	3.06	1.28	0.94	0.56	0.41	0.29	1.67	17.0 (Jun. 6)	0.19 (Dec. 31)	1978
1979	0.15	0.14	0.23	0.43	4.74	4.82	1.52	0.80	0.53	0.31	0.20	0.17	1.18	13.7 (May 27)	0.13 (Feb. 23)	1979
1980	0.16	0.13	0.13	1.94	7.72	6.22	1.44	1.33	0.81	0.79	0.37	0.27	1.79	17.2 (May 26)	0.09 (Jan. 31)	1980
MEAN	0.29	0.26	0.28	1.05	5.88	8.58	3.09	1.67	1.03	0.70	0.45	0.34	1.91	-	-	MEAN

* Station 08NK021, 104 km^2, all flows in m^{3}s^{-1}.
** 1975 values extrapolated from station 08NK025, Fording River above Clode Creek, 96 km^2

Maximum and minimum mean monthly flows are underlined.

From: Water Survey of Canada, Surface Water Data, British Columbia, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979 and 1980.

TABLE 3: NITROGEN LOSSES TO GROUNDWATER DURING LOADING OF WET BLASTHOLES WITH SLURRY EXPLOSIVES

BLASTHOLE NUMBER AND DATE	BEFORE LOADING			AFTER LOADING			NET INORGANIC NITROGEN LOSS kg N	INORGANIC NITROGEN IN EXPLOSIVES kg N	COMMENTS
	INORGANIC* NITROGEN mgL^{-1} N	VOLUME OF WATER m^3	INORGANIC NITROGEN kg N	INORGANIC NITROGEN mgL^{-1} N	VOLUME OF WATER m^3	INORGANIC NITROGEN kg N			
Nitrex 201 Slurry (24.6% nitrogen by weight)									
GW 526-60 Apr. 17/80	104.4	0.23	0.02	5530	0.08-0.23	0.4-1.2	0.4-1.2	174	
GW 527-60 Apr. 17/80	-	-	-	-	-	-	-	-	Water not sampled before loading, no water over slurry after loading.
GW 528-60 Apr. 17/80	30.8	0.19	0.01	47 000	0.34	16.0	16.0	240	Last hole of truckload, hose and mixing chamber flushed into hole.
GW 529-60 Apr. 17/80	-	-	-	2927	0.30	0.9	0.9	293	Water not sampled before loading, new truckload started.
GW 530-59 Apr. 17/80	-	-	-	-	-	-	-	-	Water not sampled before loading, no water over slurry after loading.
GW 531-55 Apr. 17/80	-	-	-	937	0.30	0.3	0.3	290	Water not sampled before loading, hose and mixing chamber flushed into hole for lunch break.
GW 532-50 Apr. 17/80	92.6	0.08	0.01	-	-	-	-	-	No water over slurry after loading.
GW 533-50 Apr. 17/80	-	-	-	977	0.30	0.3	0.3	203	Water not sampled before loading.
GW 534-50 Apr. 17/80	87.7	0.08	0.01	-	-	-	-	-	No water over slurry after loading.
GW 535-49 Apr. 17/80	-	-	-	13 000	0.45	5.8	5.8	196	Water not sampled before loading, last hole of truckload, flushed mixing chamber and hose into hole.
D-11 (Clode) Jun. 5/80	63.9	1.18	0.08	6940	0.34-1.18	2.4-8.2	2.3-8.1	430	
D-10 (Clode) Jun. 5/80	81.1	1.18	0.10	1350	0.34-1.18	0.5-1.6	0.4-1.5	430	
6-C (Clode) Jun. 5/80	80.1	0.85	0.07	846	0.34-0.85	0.3-0.7	0.2-0.6	247	Hose and mixing chamber flushed into hole.
Nitrix 201 Slurry Summary									
Maximum	104.4		0.10	47 000		16	16	430	
Minimum	30.8		0.01	937		0.3	0.3	174	
Average	77.2		0.04	8834		3.0-3.9	3.0-3.9	278	

* Dissolved inorganic nitrogen (NH_3-N + NO_3-N + NO_2-N)

TABLE 3 (CONTINUED)

BLASTHOLE NUMBER AND DATE	BEFORE LOADING			AFTER LOADING			NET INORGANIC NITROGEN LOSS kg N	INORGANIC NITROGEN IN EXPLOSIVES kg N	COMMENTS
	INORGANIC NITROGEN mgL^{-1} N	VOLUME OF WATER m^3	INORGANIC NITROGEN kg N	INORGANIC NITROGEN mgL^{-1} N	VOLUME OF WATER m^3	INORGANIC NITROGEN kg N			
Powergel A Slurry (24.0% nitrogen by weight)									
GA 469 Jul. 9/80	20.4	0.51	0.01	-	0.17-0.51	-	-	347	Interference with nitrogen analyses after loading, first hole loaded, first truck.
GA 468 Jul. 9/80	24.0	0.84	0.02	-	-	-	-	355	No water over slurry after loading.
GA 508 Jul. 9/80	18.2	1.08	0.02	461	0.61-1.08	0.3-0.5	0.3-0.5	404	
GA 549 Jul. 9/80	29.0	1.35	0.04	2870	0.46-1.35	1.3-3.9	1.3-3.8	489	
GA 548 Jul. 9/80	-	0.46	-	-	0.46-0.56	-	-	199	Water not sampled before loading intereference with nitrogen analyses after loading.
GA 588 Jul. 9/80	65.9	1.26	0.08	-	0.51-1.26	-	-	404	Interference with nitrogen analyses after loading.
GA 589 Jul. 9/80	11.8	1.70	0.02	-	-	-	-	617	Slurry floating on water after loading, could not sample.
GA 749-67 Jul. 10/80	144.6	0.78	0.11	5190	0.38-0.78	2.0-4.0	1.9-4.0	269	First hole loaded, second truck.
GA 709-67 Jul. 10/80	-	0.64	-	1495	0.35-0.64	0.5-1.0	0.5-0.9	206	Water not sampled before loading.
GA 708-67 Jul. 10/80	89.3	0.84	0.08	1420	0.43-0.84	0.6-1.2	0.5-1.1	269	
GA 668-67 Jul. 10/80	-	2.16	-	-	-	-	-	773	Water not sampled before loading, slurry floating on water after loading, could not sample.
GA 669-67 Jul. 10/80	49.7	0.78	0.04	57 800	0.40-0.78	23.3-45.1	23.2-45.0	248	Fifth hole loaded, second truck.
GA 629 Jul. 10/80	-	1.23	-	14 580	0.81-1.23	12.0-18.3	12.0-18.3	411	Water not sampled before loading, last hole loaded, second truck, mixing chamber and hose flushed on ground.
Powergel A Slurry Summary									
Maximum	144.6		0.11	57 800		23.3-45.1	23.2-45.0	773	
Minimum	11.8		0.01	461		0.28-0.51	0.3-0.5	199	
Average	29.6		0.05	12 012		5.7-10.6	5.7-10.5	384	
Combined Nitrex 201 and Powergel A Summary									
Maximum	144.6		0.11	57 800		23.3-45.1	23.2-45.0	793	
Minimum	11.8		0.01	461		0.3	0.3	174	
Average	50.4		0.05	10 224		4.2-6.8	4.2-6.8	341	

TABLE 4: NITROGEN DATA: DRAINAGE FROM NORTH OF SITE 0225083

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 10 24	MOE	0.605	0.26	<0.005	0.87	5	0.4	0.3 kgd^{-1}N average
10 25	MOE	0.56	0.25	<0.005	0.81	3.5	0.2	
80 02 26	MOE					0	0	dry
80 04 14	MOE	0.104	1.24	0.006	1.35	40	4.7	7.9 kgd^{-1}N average
04 15	MOE	0.151	3.59	0.010	3.75	41	13	
04 17	MOE	0.182	1.65	0.011	1.84	35	5.6	
80 06 03	MOE	0.089	1.27	0.006	1.37	22	2.6	2.6 kgd^{-1}N average
06 04	MOE	0.094	1.23	0.006	1.33	22	2.5	
N		7	7	7	7	8	8	
Average		0.26	1.36	0.007	1.62	-	-	
Maximum		0.605	3.59	0.011	3.75	41	13	
Minimum		0.089	0.25	<0.005	0.81	0	0	

TABLE 5: NITROGEN DATA: CLODE CREEK ABOVE CLODE POND, SITE 0225083
(FORDING COAL SITE CC4)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 10 22	MOE	0.057	4.54	0.008	4.6	0.2	0.1	1.1 kgd^{-1}N average
10 24	MOE	0.405	24.9	0.112	25.4	0.5	1.1	
10 25	MOE	0.338	12.3	0.055	12.7	2.0	2.2	
80 02 26	MOE							dry
02 27	MOE							
02 28	MOE							
80 04 14	MOE	0.154	1.32	0.046	1.5	115	15	16 kgd^{-1}N average
04 15	MOE	0.076	0.85	0.011	0.94	73	6	
04 17	MOE	0.071	1.24	0.032	1.3	225	26	
80 06 03	MOE							68 kgd^{-1}N average calculated by subtracting 0225092 and drainage north of 0225083
06 04	MOE							
06 05	MOE							

TABLE 6: NITROGEN DATA: CLODE POND INFLUENT - NORTHEAST CORNER, SITE 0225092

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 08 14	MOE	0.100	1.41	0.014	1.5	73	9.6	5.4 kgd^{-1}N average
08 15	MOE	0.034	0.90	0.009	0.94	39	3.2	
08 16	MOE	0.094	1.16	0.007	1.26	30	3.3	
79 10 24	MOE	0.154	1.34	0.009	1.5	11	1.4	1.6 kgd^{-1}N average
10 25	MOE	0.104	0.87	0.005	1.0	22	1.9	
80 02 26	MOE					0	0	dry
02 27	MOE					0	0	
02 28	MOE					0	0	
80 04 14	MOE					155	20	24 kgd^{-1}N average calculated by adding 0225083 and drainage from north of 0225083
04 15	MOE					114	22	
04 17	MOE					260	32	
80 06 03	MOE	0.261	1.41	0.008	1.7	400	58	70 kgd^{-1}N average
06 04	MOE	0.444	1.71	0.010	2.2	400	75	
06 05	MOE	0.364	1.87	0.013	2.2	400	78	
N		8	8	8	8	14	14	
Average		0.194	1.33	0.009	1.5	136	22	
Maximum		0.444	1.87	0.014	2.2	400	78	
Minimum		0.034	0.87	0.005	0.94	0	0	

TABLE 7: NITROGEN DATA: AVALANCHE CREEK AND CLODE CREEK UPSTREAM CLODE PIT

AVALANCHE CREEK (FORDING COAL SITE AC1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 05 24	FCL	<0.1	0.94	<0.003	0.94	-	-	Avalanche Creek receives drainage from hydraulic mine spoil pile
79 06 06	FCL	<0.1	0.74	<0.003	0.74	-	-	
06 20	FCL	<0.1	0.71	0.003	0.71	-	-	
79 07 04	FCL	<0.1	0.53	<0.003	0.53	-	-	
80 06 05	MOE	0.019	0.55	<0.005	0.57	12	0.6	

CLODE CREEK UPSTREAM CLODE PIT (FORDING COAL SITE CC3)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
78 05 04	FCL	<0.1	0.07	<0.003	<0.1	-	-	
78 10 30	FCL	<0.1	0.09	<0.003	<0.1	-	-	
79 03 14	FCL	0.1	0.16	<0.003	0.26	-	-	
03 28	FCL	<0.1	0.05	<0.003	<0.1	-	-	
79 04 11	FCL	<0.1	0.07	<0.003	<0.1	-	-	
79 05 10	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
05 24	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
79 06 06	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
06 20	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
79 07 04	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
79 10 23	MOE	<0.005	0.02	<0.005	0.02	-	-	
80 06 05	MOE	0.010	0.04	<0.005	0.05	183	0.8	

TABLE 8: NITROGEN DATA: #7 SPOIL DRAINAGE TO CLODE POND, SITE 0225078

(FORDING COAL SITE CC5)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 04 11	FCL	<0.1	27.6	0.009	27.6	-	-	
04 18	FCL	<0.1	31.0	0.015	31.0	-	-	
79 05 10	FCL	<0.1	34.7	0.28	35.0	-	-	
05 24	FCL	0.3	51.0	0.26	51.6	-	-	
79 06 06	FCL	<0.1	73.6	0.66	74.2	-	-	
06 20	FCL	<0.1	66.7	0.66	67.4	-	-	
79 07 04	FCL	0.1	56.4	0.75	57.2	-	-	
79 08 14	MOE	1.10	62.5	0.039	63.6	32	180	
08 15	MOE	1.02	59.4	0.055	60.5	28	150	160 kgd^{-1}N, average
08 16	MOE	-	59.0	0.047	-	27	-	
79 10 23	MOE	2.49	74.4	0.075	77.0	14	93	
10 24	MOE	2.33	72.4	0.075	74.8	14	90	90 kgd^{-1}N, average
10 25	MOE	2.38	70.4	0.073	72.9	14	88	
80 02 26	MOE	2.87	110.8	0.176	113.9	7	69	
02 27	MOE	2.35	96.0	0.154	98.6	8	68	77 kgd^{-1}N, average
02 28	MOE	2.08	88.6	0.143	90.8	12	94	
80 04 14	MOE	2.68	45.4	0.053	48.2	70	290	
04 15	MOE	3.51	57.9	0.060	61.5	70	370	380 kgd^{-1}N, average
04 17	MOE	2.81	41.9	0.079	44.8	119	460	
80 06 03	MOE	3.54	59.9	0.095	63.5	77	420	
06 04	MOE	3.70	60.9	0.081	64.7	77	430	500 kgd^{-1}N, average
06 05	MOE	3.32	56.9	0.078	60.3	125	650	
N		21	22	22	21	15	14	
Average		1.8	61.7	0.18	63.8	46	250	
Maximum		3.7	110.8	0.75	113.9	125	650	
Minimum		<0.1	27.6	0.009	27.6	7	68	

TABLE 9: NITROGEN DATA: CLODE POND DECANT, SITE PE0042407

(FORDING COAL SITE CC1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
78 06 06	FCL	<0.1	7.6	0.06	7.7	-	-	
78 07 12	FCL	<0.1	10.6	0.06	10.7	-	-	
78 08 02	FCL	<0.1	14.5	0.04	14.5	-	-	
79 05 04	FCL	<0.1	3.4	0.02	3.4	-	-	
05 16	FCL	<0.1	5.5	0.02	5.5	-	-	
79 06 13	FCL	<0.1	4.6	0.03	4.6	-	-	
80 04 14	MOE	0.36	6.7	0.016	7.0	51	31	Start of 1980
04 15	MOE	0.64	11.6	0.031	12.2	173	183	decant
04 17	MOE	0.95	14.7	0.033	15.6	188	254	156 kgd^{-1}N, average
80 06 03	MOE	0.47	6.3	0.018	6.8	390	228	
06 04	MOE	0.56	7.8	0.023	8.4	390	282	258 kgd^{-1}N, average
06 05	MOE	0.56	7.3	0.020	7.9	390	265	
80 07 23	MOE	0.43	11.3	0.066	11.8	47	48	
N		13	13	13	13	7	7	
Average		0.36	8.6	0.03	9.0	233	184	
Maximum		0.95	14.7	0.066	15.6	390	282	
Minimum		<0.1	3.4	0.020	3.4	47	31	

TABLE 10: NITROGEN DATA: CLODE POND SEEPAGE - SOUTHWEST CORNER, SITE 0200306

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 08 14	MOE	0.023	2.0	<0.005	2.0	131	23	19 kgd^{-1}N, average
08 15	MOE	0.01	2.0	<0.005	2.0	83	14	
08 16	MOE	0.015	2.3	<0.005	2.3	97	19	
79 10 23	MOE	0.007	2.2	<0.005	2.2	50	10	11 kgd^{-1}N, average
10 24	MOE	0.008	2.3	<0.005	2.3	61	12	
10 25	MOE	0.008	2.6	<0.005	2.6	53	12	
80 02 26	MOE	0.009	2.1	<0.005	2.1	19	3.5	4.2 kgd^{-1}N, average
02 27	MOE	0.013	2.2	<0.005	2.2	23	4.4	
02 28	MOE	0.012	2.3	<0.005	2.3	23	4.6	
80 04 14	MOE	0.037	7.5	0.009	7.5	102	66	85 kdg^{-1}N, average
04 15	MOE	0.054	10.1	0.014	10.2	102	90	
04 17	MOE	0.175	10.9	0.014	11.1	102	98	
80 06 03	MOE	0.020	3.3	<0.005	3.3	109	31	33 kgd^{-1}N, average
06 04	MOE	0.019	3.6	<0.005	3.7	109	35	
N		14	14	14	14	14	14	
Average		0.03	4.0	0.007	4.0	76	30	
Maximum		0.175	10.9	0.014	11.1	131	98	
Minimum		0.007	2.0	<0.005	2.0	19	3.5	

TABLE 11: NITROGEN DATA: CLODE POND SEEPAGE - SOUTH SIDE OF ROAD, SITE 0200312

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 08 14	MOE	0.018	6.8	<0.005	6.8	85	50	35 kgd^{-1}N, average
08 15	MOE	0.019	7.6	<0.005	7.6	54	35	
08 16	MOE	0.021	7.1	<0.005	7.1	33	20	
79 10 23	MOE	0.044	8.2	0.009	8.2	42	30	32 kgd^{-1}N, average
10 24	MOE	0.047	8.6	0.009	8.7	46	32	
10 25	MOE	0.034	8.4	0.008	8.4	46	34	
80 02 26	MOE	0.029	9.6	0.023	9.6	30	25	27 kgd^{-1}N, average
02 27	MOE	0.035	11.7	0.021	11.7	30	30	
02 28	MOE	0.030	10.1	0.018	10.1	30	26	
80 04 14	MOE	0.51	19.9	0.085	20.5	53	94	97 kgd^{-1}N, average
04 15	MOE	0.46	18.5	0.089	19.1	53	88	
04 17	MOE	3.64	20.3	0.082	24.0	53	110	
80 06 03	MOE	0.035	8.0	0.008	8.0	60	42	46 kgd^{-1}N, average
06 04	MOE	0.046	9.4	0.013	9.4	60	49	
N		14	14	14	14	14	14	
Average		0.36	11.0	0.027	11.4	48	48	
Maximum		3.64	20.3	0.089	24.0	85	110	
Minimum		0.018	6.8	<0.005	6.8	30	20	

TABLE 12: NITROGEN DATA: NORTH INTERCEPTOR DITCH, UPPER AND LOWER

UPPER (FORDING COAL SITE NGD1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
78 08 28	FCL	<0.1	0.14	<0.003	0.14	-	-	
78 09 20	FCL	<0.1	0.09	<0.003	<0.1	-	-	
78 10 11	FCL	<0.1	0.05	<0.003	<0.1	-	-	
10 25	FCL	<0.1	0.05	<0.003	<0.1	-	-	
79 05 10	FCL	<0.1	<0.02	0.003	<0.1	-	-	
05 24	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
79 06 06	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
06 20	FCL	<0.1	<0.02	<0.002	<0.1	-	-	
79 07 04	FCL	<0.1	<0.02	<0.003	<0.1	-	-	

LOWER (FORDING COAL SITE NGD2)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
78 08 28	FCL	<0.1	0.12	<0.003	0.12	-	-	
78 09 20	FCL	<0.1	0.21	<0.003	0.21	-	-	
78 10 11	FCL	<0.1	0.09	<0.003	<0.1	-	-	
10 25	FCL	<0.1	0.05	<0.003	<0.1	-	-	
79 05 10	FCL	0.1	<0.02	<0.003	0.1	-	-	
05 24	FCL	0.1	<0.02	<0.003	0.1	-	-	
79 06 06	FCL	0.1	<0.02	<0.003	0.1	-	-	
06 20	FCL	<0.1	0.16	<0.003	0.16	-	-	
79 07 04	FCL	<0.1	0.02	<0.003	<0.1	-	-	

TABLE 13: NITROGEN DATA: LAKE MOUNTAIN CREEK

(FORDING COAL SITE LM1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 05 10	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
05 24	FCL	0.1	<0.02	0.003	0.1	-	-	
79 06 06	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
06 20	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
79 07 04	FCL	<0.1	<0.02	<0.003	<0.1	-	-	

TABLE 14: NITROGEN DATA: NORTH INTERCEPTOR DITCH, SITE XE0200301

(FORDING COAL SITE NGD3)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
78 03 29	FCL	1.3	0.97	0.003	2.3*	-	-	
78 04 25	FCL	0.1	0.18	-	0.28	-	-	
78 05 03	FCL	-	0.07	<0.003	0.07	-	-	
78 06 12	FCL	0.1	<0.02	<0.003	0.1	-	-	
78 07 12	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
78 08 02	FCL	<0.1	0.05	0.003	0.05	-	-	
08 28	FCL	<0.1	0.12	<0.003	0.12	-	-	
78 09 20	FCL	<0.1	0.05	<0.003	<0.1	-	-	
78 10 11	FCL	<0.1	0.05	<0.003	<0.1	-	-	
10 25	FCL	<0.1	0.02	<0.003	<0.1	-	-	
79 03 28	FCL	<0.1	0.14	<0.003	0.14	-	-	
79 04 11	FCL	0.1	0.58	0.003	0.68*	-	-	
04 18	FCL	<0.1	0.23	0.003	0.23	-	-	
79 05 10	FCL	<0.1	0.09	<0.003	<0.1	-	-	
05 24	FCL	0.1	<0.02	<0.003	0.1	-	-	
79 06 06	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
06 20	FCL	<0.1	0.07	<0.003	<0.1	-	-	
79 07 04	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
79 08 14	MOE	0.006	<0.02	<0.005	<0.02	-	-	To F-seam pit
79 10 23	MOE	0.007	<0.02	<0.005	<0.02	-	-	To F-seam pit
80 02 26	MOE							Dry
80 04 14	MOE	0.055	0.12	<0.005	0.18	11	0.2	To F-seam pit
80 06 03	MOE	0.011	0.03	<0.005	0.04	630	2.2	1.9 kgd^{-1}N, average to Fording River
06 04	MOE	0.012	0.02	<0.005	0.03	630	1.6	

* Probably erroneous results

TABLE 15: NITROGEN DATA: EAGLE CREEK ABOVE EAGLE POND, SITE 0225079

(FORDING COAL SITE EC2)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
78 04 03	FCL	<0.1	1.0	0.04	1.0	-	-	
78 10 11	FCL	<0.1	46.7	0.018	46.7	-	-	
79 05 24	FCL	<0.1	2.8	<0.003	2.8	-	-	
79 06 06	FCL	<0.1	3.9	0.006	3.9	-	-	
06 20	FCL	<0.1	3.2	<0.003	3.2	-	-	
79 07 04	FCL	0.1	5.3	0.003	5.4	-	-	
79 08 14	MOE	0.021	5.1	0.005	5.2	3	1.3	1 kgd^{-1}N, average
08 16	MOE	0.023	4.7	0.006	4.7	2	0.8	
79 10 23-25	NO FLOW					0	0	
80 02 26-28	NO FLOW					0	0	
80 04 14	MOE	0.41	1.85	0.016	2.3	86	17	Surface flow
04 15	MOE	0.02	1.36	<0.005	1.4	12	1.4	Seepage 18. kgd^{-1}N,
04 15	MOE	0.34	2.04	0.012	2.4	55	11	Surface flow combined
04 17	MOE	0.17	1.65	<0.005	1.8	8	1.3	Seepage average
04 17	MOE	0.31	1.39	0.011	1.7	149	22	Surface flow
80 06 03	MOE	0.05	5.2	<0.005	5.2	5	2.2	Seepage 17. kgd^{-1}N,
06 03	MOE	0.19	4.1	0.018	4.3	35	13	Surface flow combined
06 04	MOE	0.053	5.2	<0.005	5.3	5	2.3	Seepage average
06 04	MOE	0.186	4.3	0.018	4.5	40	16	Surface flow
N		17	17	17	17	13	13	
Average		0.14	5.9	0.011	6.0	31	7	
Maximum		0.41	46.7	0.04	46.7	149	22	
Minimum		0.02	1.0	<0.003	1.0	0	0	

TABLE 16: NITROGEN DATA: #8 SPOIL DRAINAGE TO EAGLE POND, SITE 0225087

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 08 14	MOE	0.23	54.4	0.056	54.7	18	85	67 kgd^{-1}N, average
08 16	MOE	-	62.9	0.069	63.0	9	49	
79 10 23	MOE	-	67.0	0.036	67.0	8	46	39 kgd^{-1}N, average
10 24	MOE	-	67.5	0.031	67.5	8	47	
10 25	MOE	-	69.0	0.032	69.0	4	24	
80 02 26	MOE	0.44	92.5	0.030	92.9	8	64	55 kgd^{-1}N, average
02 27	MOE	0.43	72.4	0.049	72.9	8	50	
02 28	MOE	0.43	73.6	0.051	74.1	8	51	
80 04 14	MOE	0.67	77.4	0.081	78.2	5	34	31 kdg^{-1}N, average
04 15	MOE	0.60	91.9	0.074	92.6	4	32	
04 17	MOE	0.64	77.4	0.097	78.1	4	27	
80 06 03	MOE	0.51	86.9	0.098	87.5	10	76	81 kgd^{-1}N, average
06 04	MOE	0.50	97.9	0.091	98.5	10	86	
N		9	13	13	13	13	13	
Average		0.49	76.2	0.061	76.6	8	52	
Maximum		0.67	97.9	0.098	98.5	18	86	
Minimum		0.23	54.4	0.030	54.7	4	24	

TABLE 17: NITROGEN DATA: EAGLE POND SUPERNATANT, SITE 0225064

(FORDING COAL SITE EC1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
77 08 22	FCL	<0.1	10.4	0.04	10.4	-	-	
77 09 20	FCL	<0.1	13.1	0.04	13.1	-	-	
77 10 25	FCL	<0.1	15.0	0.03	15.0	-	-	
77 11 25	FCL	<0.1	19.3	0.01	19.3	-	-	
77 12 20	FCL	<0.1	29.9	0.08	30.0	-	-	
78 02 21	FCL	0.2	21.8	0.04	22.0	-	-	
78 03 29	FCL	<0.1	5.3	0.009	5.3	-	-	
78 04 04	FCL	<0.1	4.4	0.003	4.4	-	-	
04 25	FCL	<0.1	10.6	0.02	10.6	-	-	
78 08 28	FCL	<0.1	20.5	0.06	20.6	-	-	
78 09 20	FCL	<0.1	31.0	0.08	31.1	-	-	
78 10 11	FCL	<0.1	32.9	0.09	33.0	-	-	
10 25	FCL	<0.1	36.8	0.11	36.9	-	-	
79 08 09	FCL	-	15.8		15.8	-	-	
08 14	MOE	0.18	31.5	0.177	31.9	-	-	
79 09 12	FCL	0.20	36.0	0.15	36.4	-	-	
79 10 03	FCL	0.10	41.0	0.01	41.1	-	-	
10 23	MOE	-	48.3	0.156	48.5	-	-	

* Ice cover February 26, 27 and 28, 1980 - No Samples
Decanting April 14-17 and June 3-4, 1980 - See Site PE0042406 (Table 18)

TABLE 18: NITROGEN DATA: EAGLE POND DECANT, SITE PE0042406

(FORDING COAL SITE EC1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
78 05 11	FCL	<0.1	-	-	-	-	-	
78 06 06	FCL	<0.1	10.4	0.03	10.4	-	-	
78 07 12	FCL	<0.1	13.8	0.04	13.8	-	-	
78 08 02	FCL	<0.1	17.2	0.06	17.3	-	-	
79 05 16	FCL	0.1	10.6	<0.003	10.7	-	-	
05 30	FCL	<0.1	18.2	0.05	18.2	-	-	
79 06 13	FCL	<0.1	23.5	<0.003	23.5	-	-	
06 27	FCL	<0.1	24.6	0.11	24.7	-	-	
80 04 14	MOE	0.31	15.8	0.034	16.1	35	49	83 kgd^{-1}N, average
04 15	MOE	0.35	15.6	0.044	16.0	79	108	
04 17	MOE	0.36	15.2	0.042	15.6	69	93	
80 06 03	MOE	0.27	22.5	0.063	22.9	35	69	66 kgd^{-1}N, average
06 04	MOE	0.26	20.3	0.060	20.7	35	62	

TABLE 19: NITROGEN DATA: NORTH AND CENTRAL GREENHILLS PIT WATER, SITES 0225067 AND 0225068

NORTH - SITE 0225067

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
80 02 28	MOE	0.386	9.43	0.068	9.9	17	14	
80 04 15	MOE	1.02	13.47	0.032	14.5	24	30	46 kgd^{-1}N, average*
04 17	MOE	0.795	18.7	0.083	19.6	36	61	
80 06 03	MOE	0.098	20.0	0.018	20.1	40	69	71 kgd^{-1}N, average*
06 04	MOE	0.103	20.8	0.020	20.9	40	72	

* Pumped from F-seam pit to north tailing pond

CENTRAL-SITE 0225068

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 10 23	MOE	0.765	0.2	0.007	1.0	24	2.1	2.5 kgd^{-1}N, average
10 24	MOE	0.94	0.32	0.012	1.3	26	2.9	Pumped to north tailing pond

TABLE 20: NITROGEN DATA: NORTH TAILING POND SUPERNATANT, SITE 0225020

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
75 05 22	MOE	0.62	-	-	-	-	-	
75 10 08	MOE	0.273	2.1		2.4	-	-	
76 01 14	MOE	0.85	3.0		3.8	-	-	
77 01 19	MOE	1.7	4.0	0.72	6.4	-	-	
77 05 11	MOE	1.27	-	1.3	-	-	-	
77 07 07	MOE	2.16	-	1.83	-	-	-	
78 03 29	FCL	1.0	2.2	0.33	3.5	-	-	
78 05 11	FCL	0.8	10.6	0.45	11.8	-	-	
78 06 12	FCL	1.3	16.1	0.72	18.1	-	-	
78 07 12	FCL	0.9	19.6	0.45	20.9	-	-	
78 08 02	FCL	0.9	19.6	0.33	20.8	-	-	
08 28	FCL	0.4	11.0	0.39	11.8	-	-	
78 09 20	FCL	0.6	6.9	0.36	7.9	-	-	
79 03 14	FCL	0.8	0.14	0.72	1.7	-	-	
03 28	FCL	0.8	6.7	0.72	8.2	-	-	
79 08 14	MOE	0.51	11.0	0.22	11.7	-	-	
79 10 24	MOE	1.26	16.5	0.27	18.1	-	-	
80 02 26	MOE	1.36	16.9	0.176	18.5	-	-	
80 04 15	MOE	0.142	1.42	0.010	1.6	-	-	
80 06 03	MOE	0.437	8.28	0.118	8.8	-	-	

TABLE 21: NITROGEN DATA: MAINTENANCE POND DECANT (SITE PE0042404) AND SUPERNATANT (SITE 0225063)

(FORDING COAL SITE MS1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 06 13	FCL	<0.1	0.09	<0.003	<0.1	-	-	Supernatant
06 27	FCL	<0.1	0.14	<0.003	0.14	-	-	Supernatant
79 08 09	FCL	-	1.83	-	-	-	-	Supernatant
08 14	MOE	0.011	<0.02	<0.005	<0.02	-	-	Supernatant
79 09 12	FCL	<0.1	0.14	<0.01	0.14	-	-	Supernatant
79 10 03	FCL	<0.1	5.9	<0.01	5.9	-	-	Supernatant
10 24	MOE	0.254	5.35	0.248	5.8	-	-	Supernatant
80 04 15	MOE	0.81	6.26	0.138	7.2	8	5.0	5 kgd^{-1}N, average
04 17	MOE	2.03	6.27	0.132	8.4	7	5.1	Decant
80 06 03	MOE	0.35	4.61	0.187	5.2	7	3.1	3.8 kgd^{-1}N, average
06 04	MOE	0.29	4.67	0.178	5.1	10	4.4	Decant

TABLE 22: NITROGEN DATA: SEWAGE TREATMENT PLANT EFFLUENT, SITE PE0042411 (FORDING COAL SITE STP1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
78 07 12	FCL	5.9	0.18	<0.003	6.1	*	-	*Average effluent flow July 1978 to February 1980 was 455 m^3d^{-1}
78 08 02	FCL	9.3	0.12	0.006	9.4	-	-	
08 28	FCL	5.2	0.25	0.006	5.5	-	-	
78 10 11	FCL	5.0	0.14	<0.003	5.1	-	-	
10 25	FCL	9.2	0.16	<0.003	9.3	-	-	
78 11 21	FCL	4.2	0.51	0.003	4.7	-	-	
78 12 06	FCL	2.8	0.51	0.003	3.3	-	-	
79 01 23	FCL	-	0.37	0.28	-	-	-	
79 02 13	FCL	2.9	0.62	0.25	3.8	-	-	
79 03 14	FCL	2.6	11.73	<0.003	14.3	-	-	
03 14	FCL	3.9	0.23	0.003	4.1	-	-	
79 04 11	FCL	5.2	0.23	<0.003	5.4	-	-	
04 18	FCL	0.7	0.39	0.012	1.1	-	-	
79 05 04	FCL	6.0	0.09	0.003	6.1	-	-	
05 16	FCL	3.6	0.69	<0.003	4.3	-	-	
05 30	FCL	0.7	<0.02	0.003	0.7	-	-	
79 06 13	FCL	0.7	0.09	<0.003	0.8	-	-	
06 27	FCL	12.0	0.69	0.006	12.7	-	-	
79 08 09	FCL		0.23			-	-	
79 09 12	FCL	19.0	0.20	<0.01	19.2	-	-	
79 10 03	FCL	8.0	<0.05	<0.01	8.0	-	-	
79 11 07	FCL	8.3	0.1	<0.01	8.4	-	-	
79 12 06	FCL	9.4	0.3	<0.01	9.7	-	-	
80 02 18	FCL	7.7	<0.1	<0.01	7.7	-	-	
N					22			
Average					6.8			

Annual loading = 455 m^3d^{-1} x 6.8 $mgL^{-1}N$ x 365d x 10^{-3} = 1129 $kgy^{-1}N$
= 1.1 $ty^{-1}N$

TABLE 23: NITROGEN DATA: NORTH LOOP POND DECANT, SITE PE0042402

(FORDING COAL SITE NL1)

DATE	AGENCY	NH$_3$-N mgL^{-1}	NO$_3$-N mgL^{-1}	NO$_2$-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 08 14	MOE	2.32	0.92	0.082	3.3	very small	-	
79 09 12	FCL	<0.1	2.7	0.38	3.1	-	-	Supernatant
79 10 03	FCL	<0.1	2.0	0.23	2.2	-	-	Supernatant
10 23	MOE	2.81	0.95	0.036	3.8	1.2	0.4	0.4 kgd^{-1}N, average
10 25	MOE	2.78	0.76	0.032	3.6	1.2	0.4	
79 11 07	FCL	3.7	<0.1	0.02	3.7	-	-	Decant
79 12 06	FCL	11.0	<0.1	<0.01	11.0	-	-	Decant
80 02 18	FCL	7.1	0.1	0.01	7.2	-	-	Decant
02 26	MOE	2.67	0.40	0.302	3.4	5	1.5	
02 27	MOE	5.06	4.05	0.445	9.6	5	4.2	2.8 kgd^{-1}N, average
02 28	MOE	3.54	2.65	0.191	6.2	5	2.7	Decant
80 04 15	MOE	4.1	3.1	0.09	7.2	2	1.2	1 kgd^{-1}N, average
04 17	MOE	3.44	1.13	0.09	4.7	2	0.8	Decant
80 06 03	MOE	1.71	4.06	0.140	5.9	62	31	24 kgd^{-1}N, average
06 04	MOE	1.61	3.54	0.162	4.9	40	17	Decant

Note: Sewage treatment plant (PE0042411) discharged to north loop pond .

North loop pond did not decant until the fall of 1979 (infiltrated to ground prior to this time).

TABLE 24: NITROGEN DATA: CIL EXPLOSIVES PLANT SUMP, SITE 0225088*

(FORDING COAL SITE CIL1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW m^{3}d^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 05 24	FCL	6400	7820	44.4	14 264	1.6	23	
79 06 06	FCL	19 000	27 370	1.6	46 372	1.6	74	
06 20	FCL	115	704	1.2	820	1.6	1.3	
79 07 04	FCL	150	7000	2.8	7153	1.6	11	
79 08 15	MOE	1050	1239	0.9	2290	1.6	3.7	1.9 kgd^{-1}N, average
08 16	MOE	33.4	47.8	0.16	81.4	1.6	0.1	
79 10 23	MOE	3240	3714	36.3	6990	1.6	11	9.8 kgd^{-1}N, average
10 24	MOE	1000	1210	0.07	2210	1.6	3.5	
10 25	MOE	4220	5300	0.03	9520	1.6	15	
80 02 26	MOE	440	587	7.52	1035	2.1	2.2	1.7 kgd^{-1}N, average
02 27	MOE	410	569	5.78	985	2.1	2.1	
02 28	MOE	151	191	4.84	347	2.1	0.7	
80 04 15	MOE	572	748	1.49	1322	4.1	5.4	50 kgd^{-1}N, average
04 17	MOE	9850	10 698	1.80	20 550	4.6	94	
80 06 06	MOE							No results due to colour interference with colorimetric analysis
80 07 08	MOE							
N		14	14	14	14	14	14	
Average		3331	4800	7.8	8138	2.1	18	
Maximum		19 000	27 370	44.4	46 372	4.6	94	
Minimum		33.4	47.8	0.03	81	1.6	0.1	

* Pumped to South tailing pond.

TABLE 25: NITROGEN DATA: CIL EXPLOSIVES PLANT YARD DRAINAGE

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 08	MOE	8.85	12.0	0.419	21.3	1	1.8	
80 02 26	MOE	271	347	3.09	621	1	*	Hosing yard down
02 27	MOE	117	145	0.84	262	2	*	Meltwater from yard

*Loadings not calculated because flows were intermittent.

TABLE 26: NITROGEN DATA: CIL SWAMP DRAINAGE, SITE 0200305

(FORDING COAL SITE CIL2)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
77 10 25	FCL	-	62.1	0.09	-	-	-	
10 25	FCL	-	17.2	0.30	-	-	-	
77 11 30	FCL	-	28.3	-	-	-	-	
77 12 21	FCL	-	12.4	-	-	-	-	
78 02 22	FCL	-	46.5	0.11	-	-	-	
78 03 29	FCL	-	49.4	0.26	-	-	-	
78 04 25	FCL	135	43.7	0.17	179	-	-	
78 08 02	FCL	6.2	108.1	0.54	115	-	-	
08 28	FCL	-	17.9	1.56	-	-	-	
78 09 20	FCL	3.2	9.9	0.051	13.2	-	-	
79 03 21	MOE	8.9	21.2		30.1	-	-	
79 04 26	MOE	6.9	15.3		22.2	-	-	
79 05 10	FCL	5.6	32.0	0.16	37.8	-	-	
05 24	FCL	1.6	46.2	1.86	49.7	-	-	
79 06 06	FCL	1.0	66.7	0.63	68.3	-	-	
06 20	FCL	1.0	8.5	0.72	10.2	-	-	
79 07 04	FCL	0.3	7.6	0.81	8.7	-	-	
79 08 14	MOE	1.87	4.49	0.008	6.4	37	20	22 kgd^{-1}N, average entering south tailing pond via diversion channel from river.
08 15	MOE	1.88	4.89	0.01	6.8	32	19	
08 16	MOE	1.80	4.89	0.01	6.7	45	26	
79 10 23	MOE	2.58	8.39	0.01	11.0	28	27	27 kgd^{-1}N, average to Fording River
10 24	MOE	2.52	8.39	0.011	10.9	28	26	
10 25	MOE	2.62	8.49	0.011	11.1	29	28	
80 02 26	MOE	3.04	12.9	0.010	15.9	17	23	To river
02 26	MOE	5.57	18.2	0.011	23.8	23	47	Pumped to south tailings pond

TABLE 26 (CONTINUED)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
80 02 27	MOE	4.00	15.3	0.008	19.3	23	38	To river
02 27	MOE	6.57	19.7	0.008	26.3	23	52	Pumped to south tailing pond
02 28	MOE	4.04	16.2	0.009	20.2	32	56	To south tailing pond via diversion channel from river Average to river = 31 kgd^{-1}N Average to south tailings pond = 52 kgd^{-1}N Average total from CIL ditch = 72 kgd^{-1}
80 04 15	MOE	8.75	33.37	0.331	42.4	43	158	148 kgd^{-1}N, average to south tailing pond via new ditch
04 17	MOE	6.90	27.45	0.552	34.9	46	139	
80 06 03	MOE	3.32	14.12	0.084	17.52	110	166	180 kgd^{-1}N, average to river
06 04	MOE	3.90	18.51	0.088	22.5	100	194	
N		25	32	28	25	15	15	
Average		9.2	25.3	0.30	32.4	41	68	
Maximum		135	108.1	1.86	179	110	194	
Minimum		0.3	4.5	0.008	6.4	17	19	

Assumptions for Annual Loading Calculations:

Aug. - Nov. 79:	CIL ditch to south tailings pond via diversion channel from river
Dec. 79 - Feb. 80:	CIL ditch to river
Mar. - Apr. 80:	CIL ditch to south tailings pond via new ditch
May - July 80:	CIL ditch to river

Total annual loading from CIL ditch:	~ 29 tN
annual loading to river:	~ 17 tN
annual loading to south tailings pond:	~ 12 tN

TABLE 27: NITROGEN DATA: SOUTH TAILING POND SUPERNATANT, SITE 0225060

(FORDING COAL SITE TP2)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 04 11	FCL	0.6	16.6	0.48	17.7	-	-	
79 05 04	FCL	0.1	10.6	0.36	11.1	-	-	
05 10	FCL	0.6	10.6	0.36	11.6	-	-	
05 30	FCL	<0.1	10.4	<0.003	10.4	-	-	
79 06 13	FCL	<0.1	10.6	0.75	11.4	-	-	
06 27	FCL	<0.1	7.6	0.03	7.6	-	-	
79 08 09	FCL	-	10.7	-	-	-	-	
08 15	MOE	1.01	6.42	0.279	7.7	-	-	
79 09 12	FCL	0.4	5.6	0.76	6.8	-	-	
79 10 03	FCL	<0.1	3.4	0.28	3.7	-	-	
10 24	MOE	1.38	9.22	0.475	11.1	-	-	
79 11 07	FCL	2.5	10.8	0.46	13.8	-	-	
79 12 06	FCL	1.2	7.0	0.27	8.5	-	-	
80 02 18	FCL	0.7	5.4	0.45	6.6	-	-	
80 04 15	MOE	1.51	8.82	0.181	10.5	-	-	
04 17	MOE	1.30	7.41	0.185	8.9	-	-	
80 06 03	MOE	0.86	5.71	0.189	6.8	-	-	
06 04	MOE	0.92	5.71	0.192	6.8	-	-	
N		17	18	17	17			
Average		0.8	8.5	0.34	9.5			
Maximum		2.5	16.6	0.76	17.7			
Minimum		<0.1	3.4	<0.003	3.7			

Note: Pumping of tailings to south tailings pond began in mid April 1979, and recycle of supernatant from south tailings pond began in August 1979.

TABLE 28: NITROGEN DATA: SOUTH TAILING POND SEEPAGE RECYCLE, SITE 0225089

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
79 08 16	MOE	0.255	4.29	0.014	4.6	60	24	
79 10 24	MOE	0.154	4.03	0.02	4.2	60	22	
80 02 27	MOE	0.205	3.60	<0.005	3.8	60	20	
02 28	MOE	0.200	3.60	<0.005	3.8			
80 04 15	MOE	0.197	6.0	<0.005	6.2	60	23	
04 15	MOE	0.111	2.82	<0.005	2.9			
04 17	MOE	0.089	4.40	<0.005	4.5			
80 06 03	MOE	0.157	4.65	<0.005	4.8	60	25	
06 04	MOE	0.164	4.65	<0.005	4.8			
N		9	9	9	9	5	5	
Average		0.17	4.2	0.008	4.4	60	23	
Maximum		0.225	6.0	0.02	4.8	60	25	
Minimum		0.089	2.8	<0.005	2.9	60	20	

TABLE 29: NITROGEN DATA: KILMARNOCK CREEK, SITES 0200252 AND 1190042

(FORDING COAL SITE KC1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
75 05 22	MOE	0.01	0.22	-	0.23	-	-	1190042
75 06 10	MOE	0.01	0.06	-	0.07	-	-	1190042
75 07 07	MOE	0.006	0.02	-	0.03	-	-	1190042
78 07 12	FCL	<0.1	0.02	<0.003	<0.1	-	-	
78 08 02	FCL	<0.1	0.05	0.003	<0.1	-	-	
08 28	FCL	<0.1	0.16	<0.003	0.16	-	-	
78 09 20	FCL	<0.1	0.07	<0.003	<0.1	-	-	
78 10 11	FCL	<0.1	0.16	<0.003	0.16	-	-	
10 25	FCL	<0.1	0.02	<0.003	<0.1	-	-	
79 05 10	FCL	<0.1	0.16	<0.003	0.16	-	-	
05 24	FCL	<0.1	0.05	<0.003	<0.1	-	-	
79 06 06	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
06 20	FCL	<0.1	0.02	<0.003	<0.1	-	-	
79 07 04	FCL	<0.1	<0.02	<0.003	<0.1	-	-	
79 08 15	MOE	0.009	<0.02	<0.005	<0.02	-	-	1190042
79 10 23	MOE	0.011	0.07	<0.005	0.08	*	-	0200252
10 24	MOE	0.007	0.05	<0.005	0.06	*	-	0200252
80 02 27	MOE	0.083	0.27	0.011	0.36	*	-	0200252
80 04 15	MOE	0.025	0.30	<0.005	0.32	-	-	0200252
04 17	MOE	0.021	0.28	<0.005	0.30	270	7	0200252
80 06 03	MOE	0.011	0.07	<0.005	0.08	-	-	0200252
06 04	MOE	0.008	0.10	<0.005	0.11	2100	20	0200252
N		22	22	19	22			
Average		0.06	0.10	0.004	0.13			
Maximum		<0.1	0.30	0.011	0.36			
Minimum		0.006	<0.02	<0.003	<0.02			

* Kilmarnock Creek dry downstream from highway.

TABLE 30: NITROGEN DATA: SOUTH INTERCEPTOR DITCH (SWIFT CREEK), SITE XE0200401
(FORDING COAL SITE SC1)

DATE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW LS^{-1}	INORGANIC N kgd^{-1}	COMMENTS
78 06 06	FCL	0.10	<0.02	<0.003	0.10	-	-	
78 07 12	FCL	<0.1	<0.02	<0.003	<0.10	-	-	
78 08 02	FCL	<0.1	0.05	0.003	<0.10	-	-	
08 28	FCL	<0.1	0.12	0.003	0.12	-	-	
78 09 20	FCL	<0.1	0.09	<0.003	<0.1	-	-	
78 10 11	FCL	<0.1	0.09	<0.003	<0.1	-	-	
10 25	FCL	<0.1	0.02	<0.003	<0.1	-	-	
79 04 11	FCL	<0.1	1.63	0.003	1.63	-	-	First appearance of elevated N.
04 18	FCL	<0.1	1.36	0.003	1.36	-	-	
79 05 10	FCL	<0.1	0.58	<0.003	0.58	-	-	
05 24	FCL	0.2	<0.02	<0.003	0.20	-	-	
79 06 06	FCL	0.1	<0.02	<0.003	0.10	-	-	
06 20	FCL	<0.1	0.21	<0.003	0.21	-	-	
79 07 04	FCL	<0.1	0.23	0.003	0.23	-	-	
79 08 15	MOE	0.016	0.67	0.006	0.69	-	-	
79 10 23	MOE	0.010	0.42	<0.005	0.43	9	0.3	
10 24	MOE	0.010	0.34	<0.005	0.35	10	0.3	0.3 kgd^{-1}N, average
10 25	MOE	0.010	0.37	<0.005	0.38	8	0.3	
80 02 26	MOE					0	0	Dry
80 04 15	MOE	0.092	9.62	0.081	9.79	84	71	88 kgd^{-1}N, average
04 17	MOE	0.069	5.95	0.053	6.07	200	105	
80 06 03	MOE	0.024	3.40	<0.005	3.42	340	100	73 kgd^{-1}N, average
06 04	MOE	0.015	1.98	<0.005	2.00	340	59	
06 05	MOE	0.020	2.50	<0.005	2.52	340	74	
06 06	MOE	0.029	2.00	<0.005	2.03	340	60	
N		24	24	24	24	10	4	
Average		0.09	1.3	0.009	1.4	167	40	
Maximum		0.2	9.62	0.081	9.79	340	88	
Minimum		0.01	<0.02	<0.003	<0.10	0	0	

TABLE 31: NITROGEN DATA: FLOWING ARTESIAN WELL #123

DATE	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}
Aug. 15/79	3.88	<0.02	<0.005	3.88
Oct. 22/79	4.02	0.02	<0.005	4.04
Oct. 24/79	3.98	<0.02	<0.005	3.98
Oct. 25/79	3.88	<0.02	<0.005	3.88
Feb. 26/80	3.90	<0.02	0.008	3.91
Feb. 27/80	3.82	<0.02	0.007	3.83
Apr. 14/80	4.04	<0.02	<0.005	4.04
Apr. 15/80	4.10	<0.02	<0.005	4.10
Jun. 3/80	3.87	<0.02	<0.05	3.87

TABLE 32: NITROGEN DATA: WATER FROM COAL SEAMS

LOCATION	DATE	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}
Turnbull Pit Highwall	April 16/80	0.104	1.71	0.285	2.1
Clode Pit Highwall	April 16/80	1.68	4.08	0.020	5.8
		0.424	1.19	0.009	1.6
	June 5/80	3.04	10.35	0.046	13.4*
		1.70	13.02	0.077	14.8*
		0.29	2.59	0.009	2.9
		0.78	9.39	0.007	10.2*
Greenhills Pit F-Seam	July 9/80	2.95	2.12	0.055	5.1
		1.74	1.40	0.024	3.1
AVERAGE					6.6

* Possible contamination by inorganic nitrogen from explosives from #1 spoil.

TABLE 33: INORGANIC NITROGEN CONCENTRATIONS* IN THE FORDING RIVER

DATE	UPSTREAM FROM FORDING COAL	IMMEDIATELY DOWNSTREAM FROM FORDING COAL		16 km DOWNSTREAM FROM FORDING COAL	FORDING RIVER AT THE MOUTH
	SITE 0200251	SITE 0200316	SITE 0200271	SITE 0200093	SITE 0200028
August 14-16, 1979	0.07	1.3	1.3	0.8	-
October 22-25, 1979	0.06	4.3	4.2	0.8	0.5
February 25-28, 1980	0.06	8.2	8.4	0.9	0.6
April 14-17, 1980	0.08	8.8	8.3	1.2	0.5
June 3-5, 1980	<0.02	1.4	1.2	0.8	-

* All values are mgL^{-1} of NO_3-N + NO_2-N + NH_3-N.

TABLE 34: FORDING COAL LTD. - MINISTRY OF ENVIRONMENT EFFLUENT SPLIT SAMPLING, JUNE 3-4, 1980

SITE	AGENCY	NH_3-N mgL^{-1}	NO_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}
CIL ditch at	FCL	0.1	14.6	2.3	17.0
Fording River	MOE	3.32	14.12	0.084	17.52
0200305					
Clode Pond Influent	FCL	1.4	5.7	0.95	59.35
0225078	MOE	3.54	59.91	0.095	63.55
South Tailing Pond	FCL	0.7	5.3	0.19	6.19
Supernatant	MOE	0.92	5.71	0.192	6.82
0225060					

FCL: Fording Coal Ltd. Samples; shipped to Cominco Trail laboratory without preservation at ambient temperatures.

MOE: Ministry of Environment samples; frozen on day of sampling, shipped to Vancouver Laboratory in insulated coolers, thawed on arrival for analysis.

TABLE 35: NITROGEN DATA FOR GRAVE AND HARMER CREEKS DOWNSTREAM FROM B.C. COAL LTD.

SITE	DATE	NO_3-N mgL^{-1}	NH_3-N mgL^{-1}	NO_2-N mgL^{-1}	INORGANIC N mgL^{-1}	FLOW m^{3}s^{-1}	INORGANIC N kgd^{-1}
0200026	69 07 29	0.11	0.07	0.005	0.18	-	-
0200026	75 05 15	0.74	0.009	-	0.75	4.16	270
1190005	75 05 15	1.13	0.012	-	1.14	2.00	200
1190005	75 06 04	0.75	0.009	-	0.76	2.76	180
0200026	75 06 05	0.45	0.01	-	0.46	6.31	250
0200026	75 07 02	0.61	0.011	-	0.62	2.35	130
1190005	75 07 02	1.09	0.012	-	1.10	1.13	110
0200026	75 07 23	0.69	0.011	-	0.70	1.35	82
1190005	75 07 23	1.17	0.015	-	1.18	0.65	66
0200026	75 08 13	0.67	0.015	-	0.68	0.91	53
1190005	75 08 13	1.13	0.014	-	1.14	0.44	43
0200256	79 10 22	1.86	0.039	<0.005	1.90	0.21	34
0200256	79 10 25	1.33	0.015	<0.005	1.34	0.22	26
0200026	80 02 25	1.02	0.015	<0.005	1.04		
0200026	80 02 28	1.02	0.020	<0.005	1.04		
0200256	80 03 06	1.55	0.047	<0.005	1.60		
0200256	80 03 18	1.56	0.032	<0.005	1.59	0.11	15
0200026	80 04 17	0.87	0.019	<0.005	0.89	1.66	130

0200026 = 08NK019: Grave Creek near mouth
0200256 = 11900005: Harmer Creek at dam (flow = 0.48 of 08NK019 flow)

TABLE 36: SUMMARY OF ALUMINUM DATA FOR FORDING COAL LTD.

Site	Agency	Date	Dissolved Aluminum mgL^{-1}				Total Aluminum mgL^{-1}				Comments
			N	Max	Min	Mean	N	Max	Min	Mean	
North tailing pond supernatant (0224020)	MOE	1973-76	17	<0.5	<0.01	<0.1	3	0.2	<0.1	0.1	Maximum detectable value was 0.2 mgL^{-1}
Eagle Pond Supernatant	FCL	1973	8	0.1	<0.1	<0.1	2	0.2	<0.1		
#7 spoil drainage (0225078)	MOE	Oct. 23, 1979					1	0.14			Discharged to Clode settling pond
Water in drill holes in pits	MOE	Aug. 15, 1979					2	15.6	15.3	15.4	Groundwater sampled before holes loaded with explosives
CIL Sump (0225088)	MOE	Aug. 15-16,1979					2	10.3	4.5	7.4	Discharged to south tailings pond
CIL Ditch (0200305)	MOE	May 13/80	1	0.05			1	0.13			Discharged to Fording River
Fording River upstream from Fording Coal (0200110 and 0200251)	MOE	1973-77	23	<0.5	<0.01	0.06*					Maximum detectable value was 0.02 mgL^{-1}
Fording River at Fording Coal (0200040)	MOE	1973-77	19	<0.5	<0.01	0.06**					Maximum detectable value was 0.07 mgL^{-1}, May 11, 1977, all other values $\leq$0.02mgL^{-1}
Fording River downstream from Fording Coal (0200201)	MOE	1975	10	0.5	<0.01	0.06					0.5 mgL^{-1} occurred on May 11, 1977 all other values $\leq$0.02 mgL^{-1}

* Mean value is 0.01 mgL^{-1} if 2 values of <0.5 mgL^{-1} are excluded.

** Mean value is 0.015 mgL^{-1} if 2 values of <0.5 mgL^{-1} are excluded.

TABLE 37: SUMMARY OF CHROMIUM DATA FOR FORDING COAL LTD.

Site	Agency	Date	Dissolved Chromium mgL^{-1}				Total Chromium mgL^{-1}				Comments
			N	Max	Min	Mean	N	Max	Min	Mean	
North tailing pond supernatant (0225020)	MOE	1975-76	3	<0.005	<0.005	<0.005	3	<0.005	<0.005	<0.005	
CIL Sump (0225088 or CIL1)	MOE	Aug. 15-16,1979					2	0.17	0.14	0.16	Discharged to South Tailing Pond
	FCL	Apr-Aug., 1981	6	380.	0.60	79.	6	430.	0.87	89.	
CIL Ditch (0200305 or NL2)	FCL	Apr-Aug., 1981	8	<0.01	<0.01	<0.01	8	<0.01	<0.01	<0.01	Discharged to Fording River
	MOE	May 13, 1980	1	0.007			1	0.01			
#7 spoil drainage (0225078)	MOE	Oct. 23, 1979					1	<0.005			Discharged to Clode Settling Pond
Water in drill Holes in pits	MOE	Aug. 15, 1979					2	0.037	0.027	0.032	Groundwater Sampled Before Holes Loaded with Explosives
Fording River upstream from Fording Coal (0200110 and 0200251)	MOE	1976-77	4	<0.005	<0.005	<0.005	1	<0.005			
Fording River downstream from Fording Coal (0200201)	MOE	1976-77	3	<0.005	<0.005	<0.005	7	0.009	<0.005	0.006	9 of 10 values were <0.005 mgL^{-1}

APPENDIX A
METHODS

The methods used by the Ministry of Environment to measure nitrogen concentrations and flows during the August 1979 - July 1980 study period are outlined below.

1. NITROGEN CONCENTRATIONS

1.1 SAMPLE COLLECTION AND HANDLING

All samples for nitrogen analysis were grab samples collected in 1250 mL polyethylene containers provided by the Environmental Laboratory of the Ministry of Environment. The containers were rinsed 2-3 times with the water to be sampled before sample collection. The unfiltered, unpreserved samples were placed in a freezer within one to four hours of sample collection. The frozen samples were shipped in insulated coolers to the Environmental Laboratory in Vancouver via courier. Transit time from Fording Coal to the Environmental Laboratory was about 24 hours, and the samples remained frozen until arrival at the Laboratory. The samples were thawed, filtered (0.45 micron pore size filter), and analyzed for nitrogen on same day as their arrival at the Laboratory.

1.2 NITROGEN ANALYSIS

1.2.1 Ammonia

The ammonia concentration was measured by the automated colorimetric: orthotolidine method described in the Laboratory Manual[98].

Precision: 1.0 and 1.1% coefficients of variation at 0.1966 and 0.6057 mgL^{-1} N, respectively[98].

Accuracy: +1.5% relative error at 0.6 mgL^{-1} N[98].

1.2.2 Nitrite

The nitrite concentration was measured by the automated colorimetric: diazotization method described in the Laboratory Manual[98].

Precision: 0.4% coefficient of variation at 0.243 and 0.874 mgL^{-1} N[98].

Accuracy: +0.1% relative error at 0.718 mgL^{-1} N[98].

1.2.3 Nitrate

The nitrite plus nitrate concentration was measured by the automated colorimetric:cadmium reduction plus diazotization method described in the Laboratory Manual[98].

Precision: 1.8 and 0.8% coefficients of variation of 0.211 and 1.426 mgL^{-1}N, respectively[98].

Accuracy: -0.4% relative error at 1.432 mgL^{-1} N[98].

The nitrate concentration was calculated by subtracting nitrite from nitrite plus nitrate.

2. FLOW MEASUREMENT

Velocity measurements were made with a Mead Instruments Corporation, HP-302 Open Stream Velocity Probe. Velocity measurements were made at a depth from the surface of 0.6 of the water depth. In open channels, the velocity was measured at a maximum of 0.6 m intervals across the channel, with a minimum of 3 velocity measurements across the channel. Depths were measured with a metre-stick, and lengths were measured with a 15 m steel measuring tape. The flow was calculated by multiplying the velocity of each interval by its cross-sectional area, and summing the flows for all internals. The flow in culverts was calculated by multiplying the velocity measured in the middle of the culvert at 0.6 of the water depth by the cross-sectional area of the water-filled portion of the culvert.

POOR

QUALITY

ORIGINAL